ENVIRONMENTAL BENEFITS ASSOCIATED WITH CNS/ATM INITIATIVES

MODEL FOR ASSESSING GLOBAL AVIATION EMISSIONS AND POTENTIAL REDUCTION FROM CNS/ATM MEASURES

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INTRODUCTION

This report for the Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organisation(ICAO), describes the work carried out by EUROCONTROL (the European Organisation for the Safety of Air Navigation and the FAA (the U.S. Federal Aviation Administration) to quantify the impact of CNS/ATM systems on aviation global emissions.

This work is driven in part by the IPCC Special Report on Aviation and Global Atmosphere (1999), which concluded: "As the aviation industry grows more and more rapidly, the impact of air traffic operations on the global atmosphere becomes increasingly important. Efforts to control or reduce the environmental impact of air traffic have identified a range of options that might reduce the impact of aviation emissions. In particular, it is expected that improvements in air traffic management (ATM) and other enhanced operational procedures for air traffic systems could help reduce aviation fuel burn, and thereby reduce the levels of aviation emissions."

Working Group 4 (CAEP-WG4) is investigating the environmental benefits associated with planned CNS/ATM initiatives.

In 1998, the FAA performed an analysis of the emissions due to aircraft in the contiguous United States (The Impact of National Airspace System (NAS) on Aircraft Emissions, September 1998). This analysis focused on the impacts due to changes in CNS/ATM as defined in the National Airspace (NAS) Architecture 3.0. This report showed that the proposed enhancements to the U.S. Air Traffic Control (ATC) system would generate benefits in the form of improved fuel efficiency to operators and reduced pollution to society at large.

This project expanded the 1998 study into a parametric model capable of estimating global emissions and fuel usage and evaluating the impacts of various CNS/ATM enhancements. EUROCONTROL supplied the inputs necessary to evaluate the European airspace as well as assist with the evaluation of the model. In parallel with the FAA developing the parametric model, EUROCONTROL developed a simulation of the ECAC airspace. These two efforts provide a crosscheck of the results and a means of detecting errors and interpreting discrepancies.

In contrast with some previous studies in this domain, potential benefits from CNS/ATM were assessed based on published implementation strategies. In the case of the United States, NAS version 4.0 was used (reflecting updates since the original 1998 study), and for Europe (ECAC), the EUROCONTROL ATM 2000+ strategy document was referred to, to identify what could be considered achievable by 2015.

RESULTS

Within the timeframe under consideration (1999-2015), global air traffic is expected to increase by around 61% (source: FESG). In the same time period, fuel consumption and CO_2 emissions are projected to increase by just 37%.

Fuel burn and CO_2 emissions are growing less quickly than traffic because of the introduction of more efficient engine technology due to aircraft retirement and fleet expansion.

This reflects the already strong commitment of the aviation industry for fuel conservation and the consequent emission reductions.

The preliminary results of this study show that by 2015 there will be an additional benefit of around 5% fuel burn and CO_2 emission savings due to the introduction of CNS/ATM measures within U.S. and Europe.

Table ES-1 shows a summary of the annual fuel and CO_2 savings for 2015 from CNS/ATM improvements for both the United States (CONUS) and Europe (ECAC). The results are displayed by flight segment.

Table ES-1. Percent Annual Fuel & CO_2 Savings by 2015 due to CNS/ATM Enhancements

Flight segment	CONUS	ECAC
Above 3000’	5 %	4 %
Below 3000’	5 %	7 %
Surface	11 %	3%
Whole flight	5 %	5 %

Preliminary results show savings of a similar order of magnitude for NO_X, HC and CO, but all the work is subject to further analysis, verification and validation.

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1.0 INTRODUCTION

This report describes the joint European Organisation of the Safety of Air Navigation (EUROCONTROL) and the U.S. Federal Aviation Administration (FAA) efforts to develop a common methodology and assessment tool for estimating and scaling the emissions due to worldwide air travel, along with initial results. The study is being conducted under the auspices of Working Group 4 (WG4) of the Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organisation (ICAO).

2.0 BACKGROUND

"As the aviation industry grows more and more rapidly, the impact of air traffic operations on the global atmosphere becomes increasingly important. Efforts to control or reduce the environmental impact of air traffic have identified a range of options that might reduce the impact of aviation emissions. In particular, it is expected that improvements in air traffic management (ATM) and other enhanced operational procedures for air traffic systems could help reduce aviation fuel burn, and thereby reduce the levels of aviation emissions." [13]

Working Group 4 (CAEP-WG4) is investigating the environmental benefits associated with planned Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) initiatives. In support of CAEP-WG4 activities, EUROCONTROL and the FAA established a joint project to develop a preliminary common methodology to quantify the potential fuel consumption and gaseous emissions reductions arising from Communication Navigation Surveillance/Air Traffic Management (CNS/ATM) systems. These systems have the potential to result in environmental benefits.

In 1998, the FAA released a study [1] of fuel consumption and emissions (nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO)) that evaluated the impact of the National Airspace System (NAS) modernisation. The analysis was limited to flights originating or ending in the contiguous United States (CONUS). The study was conducted using actual flight data and the NAS Performance Capability (NASPAC), a discrete-event simulation model and compared baseline fuel consumption and emissions for the years 1996, 2005, 2010, and 2015 to the optimal cases (i.e., NAS modernisation efforts assumed to be completed on schedule.) Both scenarios incorporated planned physical improvements, fleet changes, and increased engine efficiencies.

This project proposed expanding the 1998 study into a parametric model capable of estimating global emissions and fuel usage and evaluating the impact of various CNS/ATM measures. EUROCONTROL would supply the input necessary to evaluate the European airspace as well as assist with the evaluation of the model.

In parallel with the FAA developing the parametric model, EUROCONTROL would develop a simulation of the European airspace (hereinafter called the European simulation). These two efforts were intended to provide a crosscheck of the results and a means of detecting errors and interpreting discrepancies.

3.0 OBJECTIVES

Following the CAEP-WG4 agenda, the objective was to prepare a modeling capability to quantify the impact of CNS/ATM systems on global emissions. This capability is the first step toward a common emissions methodology that can be used globally to evaluate the impact CNS/ATM systems on reducing the fuel consumption and related emissions. Carbon dioxide (CO_2) is the emission of primary concern. Other emissions included in this study are NO_x, CO, and HC.

Both the FAA and EUROCONTROL have strategic roles in CNS/ATM measures (i.e., ATM 2000+ in Europe and the NAS Architecture in the U.S.). Understanding the commonalties and differences between the U.S. and European planned CNS/ATM measures is key to building the parametric model and applying the simulation results of different scenarios from one region to the other. Thus, one of the objectives of this joint project is to identify first the relevant planned CNS/ATM measures for both regions and then compare the implementation schedule.

3.1 Parametric Model

The primary objectives of the parametric model include:

?? Quantifying the relative environmental benefits arising from CNS/ATM systems efficiently and accurately.

?? Updating and enhancing emission results for the U.S. obtained by the FAA [1] in accordance with the most current NAS Architecture.

?? Providing the ability to perform sensitivity analyses. For example, allowing the user to change the demand forecast or the estimated impact of a CNS/ATM initiative on airport capacity to evaluate the effect on fuel usage.

?? Incorporating European information into the emissions model and estimate the European environmental benefits arising from the use of CNS/ATM initiatives.

?? Estimating a global aircraft emissions baseline using the Official Airline Guide (OAG).

3.2 The European Simulation Model

Overall objectives for the simulation of European airspace include:

?? Conducting a conventional simulation study to calculate European fuel burn and emissions to provide data for comparison with and cross-validation of the parametric model.

?? Cooperating with the FAA to develop a common methodology to quantify environmental benefits arising from CNS/ATM systems for WG4.

4.0 TECHNICAL APPROACH

The ICAO CAEP-WG 4 "Emission and Operational Issues" is charged with addressing the issue of reducing fuel burn by civil aviation through operational measures, which include improvements of CNS/ATM systems. Cooperation between the FAA and EUROCONTROL was key to the success of this mission. Therefore, in October 1999, the FAA and EUROCONTROL signed an agreement on the development of a preliminary common methodology to quantify environmental benefits arising from CNS/ATM initiatives.

Sections 4.1 and 4.2 describe a summary of the parametric model and the European simulation respectively. Section 4.3 lists parameters, inputs, and assumptions used by the parametric model and simulations.

4.1 The Parametric Model

4.1.1 Basis of Model

The following sections provide a summary of the parametric model, assumptions and the inputs. Appendix G describes the methodology in detail. Implementation of the model is presented in Appendix H.

CNS/ATM measures may affect three areas:

- Airport capacities - Increasing airport capacities, thereby reducing delay at congested airports
- Cruise times – Shortening cruise times through greater use of direct routes and therefore, sector delay reduction
- Taxi-times – reducing unimpeded taxi-times

The list below identifies the CNS/ATM initiatives for each category above.

In the earlier study [1], the bulk of fuel savings came from delay reductions and shortening the cruise time at higher altitudes. In the U.S., these future CNS/ATM initiatives are assumed to increase airport capacities, resulting in delay reductions at congested airports:

- Precision Runway Monitor (PRM)
- Center-TRACON Automation System (CTAS)
- Integrated Terminal Weather System (ITWS)
- Automatic Dependent Surveillance–Broadcast (ADS-B/CDTI)
- Wide Area/Local Area Augmentation (WAAS/LAAS)

?? Procedural airport improvement

?? Reduced Vertical Separation Minima (RVSM) and Wind–Optimized Direct Routes will result in shorter cruise times.

In Europe, a similar list applies as follows:

The following are procedural changes and those that affect sector capacities:

?? Route network optimization through reduced separations

?? ACT sector organisation

?? Utilization of user-preferred trajectory

?? Terminal airspace optimization

?? Airspace management and civil/military coordination

?? Enhanced tactical ATFM

?? Collaborative flight planning and re-routing

?? Strategic capacity management

?? Enhanced tactical and planning control by improved ATC decision support

?? Improve communication and surveillance support

?? Delegated airborne separation assurance

These CNS/ATM initiatives increase capacities, resulting in delay reductions at the capacity constrained airports:

?? Arrival and departure management

?? Reduced separations at airports

?? Improved sequencing and metering at airports

?? Integrated airport capacity management

Table 4.1.1-1 compares U.S. and European CNS/ATM initiatives - highlighting the commonalities and differences between planned U.S. and European CNS/ATM measures. The table allows the study group to make necessary adjustments to U.S. simulation results [1] for use in the optimal scenarios in Europe. Note that the percentage increases in sector capacities at European centers (ACCs) are overlapping and not additive. Note also that the table was developed using expert judgment and will be updated as more information becomes available.

Table 4.1.1-1. U.S. and Europe Architecture

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
Route Network Optimisation through Reduced Separation	Reduced Vertical Separation	2002	RVSM Selected Domestic Airspace	06/01/2007	ECAC-wide	15%	
	Reduced Horizontal Spacing	2007	Reduced En Route Horizontal Separation Standards	06/01/2007	Individual	5%	
ATC Sector Organisation	Provide additional sectors	2000			Individual	5-15 %	
	Align sectors with particular traffic Flows	2004			Collaborative becoming ECAC wide	5-15 %	
	Sectors adapted to airspace changes	2008			Collaborative becoming ECAC wide	5-15 %	
Use of User Preferred Trajectories	Free Routing	2003(8 States)	Current En Route Separation	06/01/1994	Collaborative	15%	
Terminal Airspace Optimisation	Structured Routes in TMAs	2005	New Direct Terminal Area Routes (charted)	06/01/2001	Individual	tbd	
	Structured Routes in TMAs	2005	FMS Departure Procedure	06/01/2002			

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
	Dynamic Management of TMAs	2008	Dynamic Resectorization	06/01/2015	Individual	5-15 %	
Airspace Management and Civil/Military Coordination	Collaborative Airspace Planning	2003 (FUA Level 1)	Sector Loading Prediction by Center	06/01/2004	Individual becoming ECAC wide	5%	
Airspace Management and Civil/Military Coordination	Collaborative Airspace Planning	2010 (ECAC Wide)	Dynamic Density/Airspace Complexity Predictor	06/01/2013			
	Enhancements to Flexible Use of Airspace Concept	2000 (Civ/Mil Co-or) 2005 (FUA lower); 2008 (Dynamic AA-ECAC-wide)			Individual becoming ECAC wide	5-15 %	
	Delegation of Airspace	2000	Flexible Airspace Management	06/01/2007	Collaborative	15%	

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
Enhanced Tactical ATFM	More effective protection of ATC through enhanced accuracy of input data and flexibility of response	2001 (Core Area) 2005 (Full Implementation)			Collaborative becoming ECAC wide	2%-4% ECAC wide	
Collaborative Flight Planning & Re-Routing	Enhanced Re-Routing Facilities	2000	Collaborative Rerouting	06/01/2002	ECAC-wide	5%	
Strategic Capacity Management	Collaborative Pre-Tactical ATM Planning	2005			Collaborative	tbd	
	Integration of Flow & Capacity Management with Airport Scheduling	2010	Delay Program Management	06/01/2002	Collaborative	tbd	
Enhanced Tactical & Planning Control by Improved ATC Decision Support	Use of automated support for Conflict Detection	2000	Conflict Probe	06/01/2004	Individual becoming Collaborative	5-15 %	
	Use of automated support for Conflict Resolution	2004	CP w/ Spacing	06/01/2006	Individual becoming Collaborative	5-15 %	

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
	Enhancement of tools through Aircraft Derived Data	2005	Integrated En Route Surveillance with ADS-B	06/01/2007	Individual	5-15 %	
Improved Communications and Surveillance Support	Use of automated communications to reduce controller workload	2000 (ground-ground) 2004 (air-ground, ATN based)	CPDLC Build 1A	06/01/2003	Individual becoming Collaborative	5%	
Improved Communications and Surveillance Support	Enhanced quality of Surveillance	2001	Improved Terminal Surveillance (Asterix/SI)	06/01/2003	Collaborative	5-15 %	
Improved Communications and Surveillance Support	Enhanced quality of Surveillance	2001	Improved En Route Surveillance (Asterix/SI)	06/01/2004			

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
Arrival & Departure Management	Use of automated tools to support Arrivals Management	2000	pFAST (FFP1)	06/01/2000	Individual	5%	0.50%
Arrival & Departure Management	Use of automated tools to support Arrivals Management		National pFAST	06/01/2004			
	Use of automated tools to support Departure Management	2000			Individual	5-15 %	0.50%
Delegated Airborne Separation Assurance	Limited delegation/transfer of Separation Assurance Responsibility	2008			Collaborative	tbd	
	Provision of Autonomy to Aircraft in Free Flight Airspace	2015			Collaborative	tbd	
Applying Best Practice following Benchmarking	Applying Best Practice following Benchmarking	2000			Individual	15%	

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
Reduced Separations at Airports	Flexible Runway Procedures	2000; 2002(widely available)			Individual		1.5%
	Enhancements arising from Airport & Runway Studies	2001	Runway Incursion Reductions - Detection Equipment	06/01/2003	Individual		0.50%
	Enhanced Wake Vortex Procedures	2008	aFAST with Wake Vortex	06/01/2009	Individual		1.50%
Improved Sequencing & Metering at Airports	Use of automated tools to support Surface Management	2000	SMS	06/01/2006	Individual		0.50%
	Use of automated support for integrated arrival, departure and surface movement management	2004	Integrated Tower Area Surveillance	06/01/2008	Individual		
Integrated Airport Capacity Management	Collaborative Information and Gate management	2000	Initial SMA (FFP1)	06/01/1998	Individual		1.50%
	All Weather Operations at Airports	2000 (not yet widely available)	SMS	06/01/2006	Individual		1.5 % (in poor weather)

Table 4.1.1-1. U.S. and Europe Architecture, Cont'd

U.S.			Europe				
Improvement Dimension	Operational Improvements (OI)	OI Timing	Architecture Implementation Name	Implementation Timing	OI Applicability	% Capacity Benefit at ACCs	% Capacity Benefit at Airports Operating at Close to Max Utilization
	All Weather Operations at Airports	2001 (not yet widely available)	Enhanced SMS	06/01/2011			
Mitigation of Environmental Constraints	Efficient management of the available environmental capacity at airports	2004			Individual		0.5-1.5 %

4.1.2 Summary of Methodology

Ground rules were established to evaluate the impact of CNS/ATM initiatives. These initiatives have the potential to increase airport capacities and thereby reduce delay at congested airports; shorten cruise times through the use of direct routes and sector delay reductions; and to reduce unimpeded taxi-times.

The scope of this study includes baseline and optimized scenarios for years 1999, 2007, 2010 and 2015. A baseline scenario is a case without CNS/ATM initiatives, but with non-CNS/ATM measures such as an additional runway or aircraft engine improvements included. An optimized scenario is defined as a scenario that incorporates planned CNS/ATM measures as well as the non-CNS/ATM measures included in the baseline scenario.

In the parametric model, variables that directly influence fuel consumption are identified as follows:

?? Phase of flight
  o Surface (taxi-in and taxi-out)
  o Take-off
  o Initial Climb below 3,000 feet (914.4 Meters)
  o Cruise, phase of flight occurring above 3,000 feet (914.4 Meters)
  o Final Approach below 3,000 feet (914.4 Meters)
  o Aircraft type and engine

?? Delays

?? Ground delays (taxi-in and taxi-out delays)

?? Approach delays (air holds in the "last tier" due to congestion at the destination airports)

?? Demand (the number of current and forecasted flights between city pairs)

?? Traffic growth rate (using Forecast and Economics Sub Group (FESG) annual growth rate)

?? Rate of improvement in aircraft performance and fleet mix changes (using FESG's assumption of a 20% total reduction in fuel burn rates in the next 20 years)

Other variables, such as airport capacity and weather conditions, can impact one of the direct variables described above. For example, demand growth and airport capacities can affect ground and arrival delays. CNS/ATM measures may increase airport capacities. Queueing theory approximations are used to estimate the percent delay changes due to capacity or demand increases. Similarly, airport capacities under Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) conditions are estimated for the baseline and optimized scenarios.

The simulation outputs of the FAA [1] are used to estimate the fuel burn rates and flight times for various phases of flight and aircraft types (more specifically the statistical analysis of the data produced, the median (i.e., 50th percentile), low (16th percentile) and high (86th percentile) of the fuel burn rates for the cruise phase of flight (i.e., above 3,000 feet)). These results are used for both the baseline and optimized scenarios. Furthermore, the simulation data are used to estimate similar statistics on travel times; for example, the median cruise time per great circle mile (note that the actual route flown is greater than the great circle distance) for a B757 aircraft for the 2010 optimized scenario. Some of these variables are calibrated to better represent Europe. The simulation in the FAA used actual trajectories for the baseline scenario. Optimized trajectory Generator (OPGEN) was used to produce flight trajectories for optimized scenarios.

The fuel burn and emissions calculated using the parametric model for U.S., Europe, and the rest of the world are displayed in section 5. The fuel and emissions savings due to CNS/ATM initiatives for U.S. and Europe can also be found in section 5.

4.2 European Simulation Model

4.2.1 Objectives

The specific objectives of this model are to

- ?? Determine a methodology to estimate air traffic fuel burn and emissions based on realistic and representative traffic movements.
- ?? Calculate fuel burn and emissions for baseline 1999 and future years 2005, 2010, and 2015 in the ECAC area.
- ?? Use the results for the validation of parametric model results.
- ?? Consider CNS/ATM measures in future calculations.

4.2.2 Summary of Methodology

The aim of the project is to produce a model that permits calculation of emissions for a baseline scenario for baseline and future years. The model can be calibrated to provide realistic results for the ECAC area that corresponds to known figures in that area. Having achieved this, forecast information for future traffic and models of future ATM concepts can be applied to allow the prediction of emissions that can be expected in future years. As a starting point, a tool that allows the calculation of realistic 4D-flight profiles for all flights in the ECAC area is used. This tool also provides a suitable model of ATM operations in the region, and therefore results in a realistic set of profiles that are characteristic of ECAC area operations. All flights in the ECAC area for a number of representative days are considered.

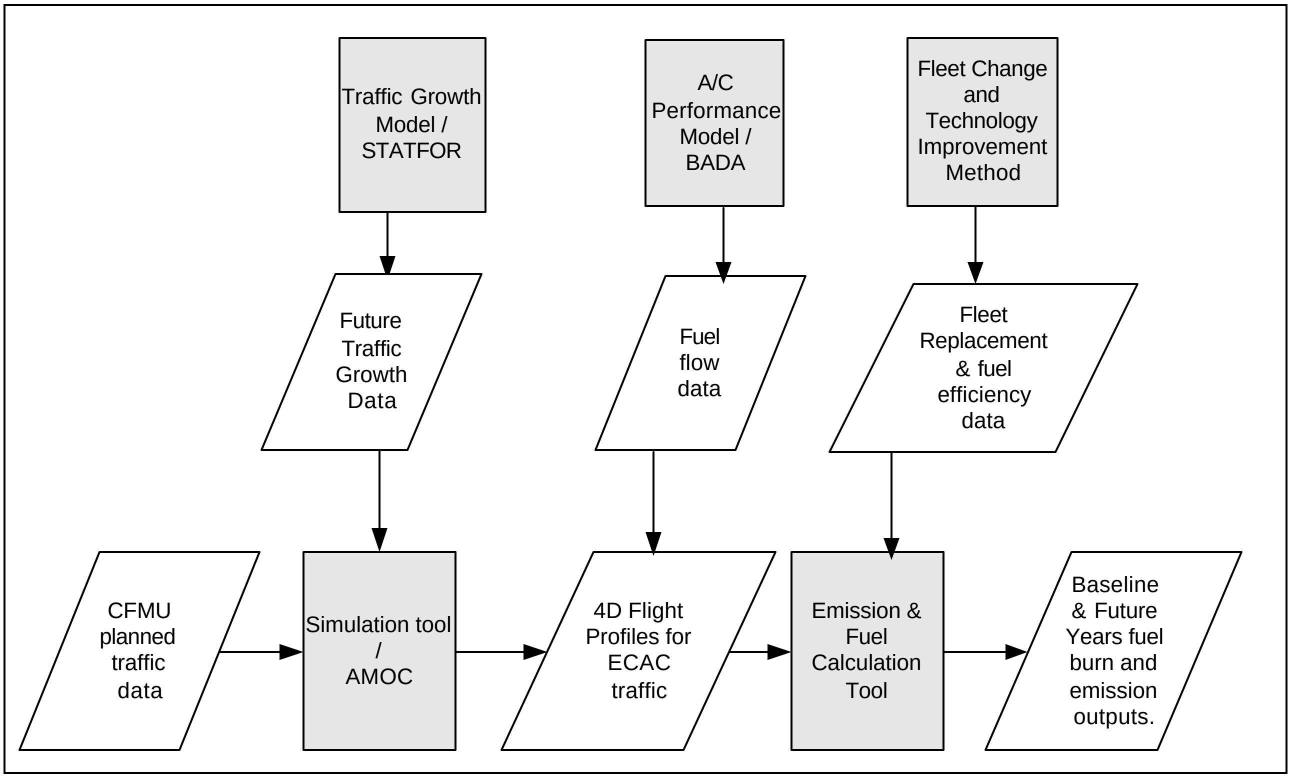

Figure 4.2.2-1. Flow Process for Emission Calculation

To generate the flight profiles in this area, the ATFM Modeling Capacity (AMOC) simulation tool is used with different modules that calculate the corresponding flow, allocate the slots, and apply delays according to the European ATM paradigm. The resulting 4D traffic profiles are considered to be representative of typical ECAC traffic movements (see Figure 4.2.2-1).

Once the baseline model has been calibrated sufficiently to ensure realistic behavior, future traffic samples can be generated using traffic forecasts from a variety of sources. At this stage, ATM 2000+ system benefits are listed but not computed since many of these concepts are still being finalised, making quantification of those systems difficult.

Traffic files for ECAC area consist of more than 200 different aircraft types. However in the model for fuel flow and emission calculation, some representative aircraft types are used because those data are not available for all aircraft types. Therefore aircraft types without such information are matched to the list of aircraft/engine type (see Appendix B).

An additional consideration in generating future traffic samples is the appearance of new more efficient aircraft types due to modernisation and fleet expansion. To account for this effect, the "Fleet Change Method" was developed (see Figure 4.2.2-2). The fleet change method determines the proportion of the future fleet that will be new compared with the existing (baseline) aircraft. Once this proportion is determined, applying the "Technological Improvement Method" allows us to estimate technological improvements, and therefore increased fuel and emission efficiency (see Appendix C) due to these technological improvements. For future traffic, the fleet change and technological improvement methods results are implemented prior to the application of the AEM to produce more realistic fuel burn and emission values.

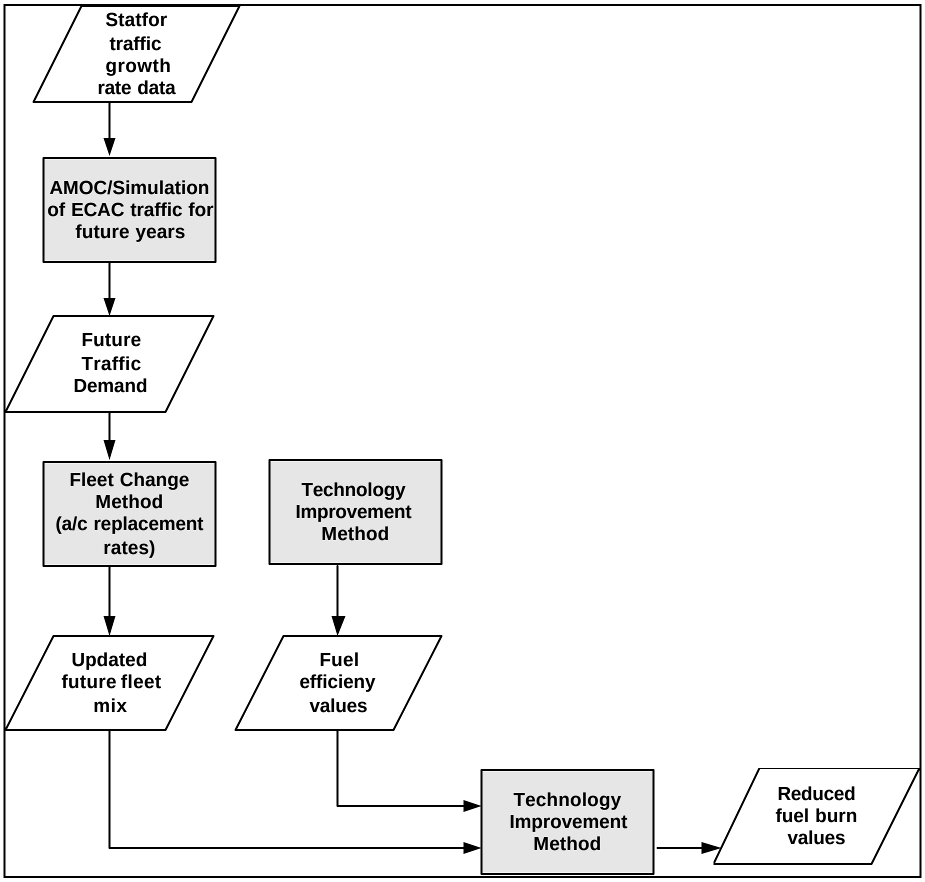

Figure 4.2.2-2. Fleet Change and Technology Improvement Approach

For particular types of emissions, CO_2, H_2O, and SO_2, the emission indices are found from various publications. Because these emissions are direct oxidation products of fuel burn, the emission indices are a constant index in any mode of flight (see Appendix D).

The Advanced Emission Model (AEM) uses the flight profile information to calculate fuel burn and emissions produced during the different flight phases. For the Landing and Take-Off (LTO) phase, ICAO emission indices are used; and for the cruise phase, Boeing Method 2 (BM2) indices are used to calculate emissions. Operational taxi time data, where available, are used instead of the idle phase. Details of the emission calculation are provided in Appendix B.2.

The final results consider baseline and future year fuel burn and emissions for three representative days, but, as stated previously, do not consider improvements due to ATM 2000+ concepts at this stage. We believe that our results are realistic for representation of Europe because simulation is made on a flight-by-flight basis, and the data comprise the whole ECAC area.

4.3 Approach, Input, and Assumptions for FAA and EUROCONTROL

In this subsection, parametric and European simulation approach/methodologies, input, and assumptions are highlighted.

4.3.1 Tools

Table 4.3.1-1. List of Models/Tools

Parametric	European Simulation
	Used ATFM simulation flight. The flight based on AMOC.
Used 1998 FAA study [1] simulation results to calculate median, low, and high time and fuel burn rate per phases of flights, aircraft type, and optimal or baseline scenarios.	Used AEM to calculate fuel burn and the emissions by flight profile information.
Used ICAO fuel burn rate and emission coefficients (lbs./min) for phase of flight below 3,000 feet.	Used ICAO fuel burn rate and emission coefficients for take-off and idle phase below 3,000 feet.
	Used BADA fuel flow data for above 3,000 feet.
Predicted future demand forecast using FESG.	Used STATFOR model to predict the future demand forecast.
Used the delay model (see Section G.9) to estimate the % change in delay due to capacity and demand changes.	
Used the FESG assumption of 1% annual reduction in emissions due to engine efficiency.	Used the fleet change and technology improvement methods to calculate fleet modernisation and technological improvement in fuel efficiency.

4.3.2 Input Data

The following summarises the input gathered by the FAA and EUROCONTROL. Included in this data is input from previous simulations and studies.

FAA input data are as follows:

- ?? Used ICAO fuel burn rates (lbs./min) for phase of flight; idle, take-off, climb (up to 3,000 feet) and approach [12].
- ?? Assumed that minimum take-off, climb, and approach times are .7, 2.2, and 4 minutes, respectively.
- ?? For “cruise” phase median, low, and high fuel burn rate (lbs./min) for existing aircraft types using all flights, and flights between city pairs of less than 500 miles great circle distance are used.
- ?? Mapped all aircraft types with unknown fuel burn rates to similar known ones, when possible, otherwise used BE58 as a default (see Appendix G, Table G.2-1).
- ?? The amount of delay on the ground (taxi) and on approach (arrival delay due to congestion at the airport) for major airports only.

?? Current and future airport VFR capacities and improvements are expected to result from airport capacity changes, physical, procedural, and CNS/ATM initiatives. For major airports, only 80 U.S. [5] and approximately 20 European airports [2] were considered.

?? List of constrained airports for Europe (see Appendix G, Table G.9.2-1).

?? For unimpeded taxi times for major airports, used the FAA's Office of Policy and Planning (FAA/APO) estimates for the U.S. In Europe, used EUROCONTROL Central Flow Management Unit (CFMU) taxi times where available.

?? Used airport weather information [4] to estimate airport capacity (average VFR and IFR).

?? Used FESG [3] for future demand forecast.

?? Used the FESG forecast [3] for fleet mix changes.

?? For 1999, based demand (flights) on ETMS [9] and CFMU [10] for the U.S. and Europe, respectively. The demand was taken from the OAG for the rest of the world.

?? Estimated the 1999 approach delays AEA reports (see Appendix G, section G.12.2)

?? Estimated taxi-out and taxi-in delays based on data provided by EUROCONTROL.

?? Used FESG assumption of 1% annual reduction in fuel burn due to engine improvements and fleet mix changes.

?? Assumed that ECAC states represent Europe region for FESG fleet and flight growth rate forecast.

?? Used current routes for baseline scenarios (U.S. and Europe).

?? Calculated optimal routes for optimal scenarios using U.S. simulations results.

?? Mapped known aircraft engines to the ICAO and BM2 default engines.

?? Calculated fuel burn and emissions while engine is on, therefore emissions generated from APU are not considered.

EUROCONTROL inputs different from the parametric model are listed below:

?? STATFOR growth rates versus FESG (STATFOR considers <50 seats as well)

?? Used operational data and CFMU nominal taxi times where available.

?? Used the average taxi value of (operational + CFMU) for the airports without any taxi information.

?? Used current CFMU values for airspace and airport capacities in ATFM simulation.

?? Based fuel burn calculation on "Real" route and profile flown.

?? Used fuel burn rates from BADA aircraft performance model.

?? Aircraft mapping

?? ATFM system impact accounted for (level restrictions, rerouting, departure delays)

?? Fleet Change and Technology Improvement Method

4.3.3 Parameters

Table 4.3.3-1. List of Parameters/Coefficients

Parametric	European Simulation
CNS/ATM initiatives and their affect on airport capacities	
Route distances	Gate to gate trajectories (simulation)
Travel times, by aircraft type, per phases of flights	Flight profile leg times per attitude
Airport (IFR and VFR) capacities	Airport capacities (simulation)
Surface weather conditions	Sector capacities (simulation)
Ground and arrival delays for the simulation base year	Congested areas (simulation)
Unimpeded taxi times	Operational and CFMU default taxi data
Fuel burn rate per aircraft type and phases of flight	Fuel burn rate per aircraft type, flight level band and attitude
IFR flights, U.S. and Europe. Scheduled flights (OAG) for the rest of the world	IFR flights
	Air Traffic Flow Management rules

4.3.4 Assumptions

The following is a summary of the assumptions used in the parametric model:

?? CNS/ATM planned capabilities in the NAS Architecture and ATM 2000+ will be implemented in the U.S. and Europe. The efficiency benefits claimed in this study from CNS/ATM capabilities will be realized.

?? Primary assumptions for the parametric emissions study are based on the study performed by the FAA in 1998. The most important assumption is the use of the previous results to develop the initial parameters for the parametric model.

?? CNS/ATM measures will improve flight efficiency in three areas: may reduce cruise time due to direct and therefore shorter flights; may reduce taxi-out delay, as well as arrival delay during final approach due to increased airport capacity; and may reduce unimpeded taxi-time.

?? CNS/ATM measures may reduce cruise time (flight above 3,000 feet), but not the fuel consumption rate (fuel usage per minute of operations) or take-off, climb, and unimpeded approach (approach without delay) time.

?? Engine design and fleet changes can contribute to fuel consumption rate improvements. FESG assumptions of 20% reduction in fuel burn rates in the next 20 years due to engine improvements and fleet mix changes are used. This reduction is included in both baseline and optimal scenarios.

?? Delay reduction as a result of airport capacity increases due to additional runways and procedural changes are included in both baseline and optimal cases and not included in percent reduction due to CNS/ATM measures.

?? Median, low, and high fuel burn rate (lbs./min) and time for each aircraft type and LTO phase of flight are the same for U.S., Europe, and the rest of the world.

?? The cruise phase of domestic Europe and intra-European flights are similar to U.S. city pairs less than 500 miles apart (great circle distance).

?? Since the en route CNS/ATM measures are similar for Europe and U.S., the optimal cases are the same for U.S. and Europe - using U.S. city pairs 500 miles apart as stated above.

?? No taxi-out or arrival delay during final approach occurs for non-constraint airports (see Appendix G, Table G.9.2-1). Similarly, all the airports outside the 80 in U.S. [5] have unlimited capacity; therefore, no delay occurs in those airports.

?? Current and future airport capacity of European Airports, provided by the European Database of Major Airports [2], only includes procedural changes and additional runways. Thus, it does not include enhancements due to CNS/ATM measures.

?? In Europe, CFMU taxi-out times as unimpeded.

?? Assumed that no taxi-in delay exists for European airports.

?? For constrained airports in Europe, airport capacity increases due to CNS/ATM measures are independent and therefore additive. This is an input to the model and can be adjusted easily if found not true.

?? For the U.S., the FESG [3] fleet and flight growth rate forecast for "Domestic North America", "intra North America", "Trans-Atlantic", "Trans-Pacific", and "North to South America" were used. This means that we assumed that growth rate is the same for U.S., Canada, and Mexico. For Europe, we used "Domestic Europe", "intra-Europe", "Europe-Middle East", "Europe-Africa", "Europe Asia Pacific", "North Atlantic", and "Mid South Atlantic". This means that we assumed that FESG calls ECAC states Europe like we do.

?? Airport IFR airport capacity is 68% of VFR airport capacity in Europe.

?? When the weather information was not available, the closest airport, preferably in the same country, was used (see Appendix G, Table G.10-1).

?? Similar to U.S., en route delay for Europe is negligible.

?? VFR flights and military flights are not included.

?? In Europe, 1999 approach delays are estimated using AEA reports (see Appendix G, section G.12.2.).

?? Current routes are used for baseline scenarios (U.S. and Europe).

?? Using U.S. simulations results, optimal routes are calculated for optimal scenarios.

?? In the U.S. portion, the segment of flights in CONUS is considered. In the European portion, the segment of flights in ECAC area is considered.

?? Fuel burn and emissions are calculated while the engine is on, therefore emissions generated from APU are not considered.

The followings are assumptions used in EUROCONTROL simulations:

?? There is no en route delay - CFMU data used.

?? VFR flights are not used.

?? Aircraft types without the information below are mapped to BADA representative aircraft or BM2 aircraft grouping.

?? Non-identified aircraft types and some helicopter and military aircraft types without performance data are not used.

?? Representative days are used for the simulation of ECAC area.

?? Estimate future fuel burn efficiency using technology improvement method values described in Appendix C.

?? ECAC states represent the European region.

?? Current routes are taken into account (ATFM slot allocation).

?? Long distance flights taking off during the simulation period outside ECAC area are reduced for those flight legs that are outside of the geographical area.

?? From the simulation output file, all flight profile legs appearing later than the simulation day are eliminated.

?? Known aircraft engines are mapped to the ICAO and BM2 default engines.

?? Fuel burn and emissions are calculated while the engine is on, therefore emissions generated from APU are not considered.

5.0 RESULTS

Section 5.1 provides initial results obtained by parametric model and an example of the sensitivity analysis. Section 5.2 details European simulation results. Section 5.3 discusses issues associated with the comparison of results.

5.1 Parametric Results

Tables 5.1-1 through 5.1-8 display fuel burn and emissions calculated by the parametric model for the U.S., Europe, and the rest of the world. Low, median, and high estimates are provided for total fuel burn and emissions by phase of flight: above 3,000', below 3,000', and surface. The low estimates are based on all parameters set to their "low", such as 16th percentile values. The median estimates are based on median values. The high estimates are based on "high", such as, 86th percentile, values. Thus, the low and high estimates are truly low and high with very high probabilities.

Tables 5.1-1, 5.1-3, and 5.1-5 list the estimates for baseline scenarios for Europe, the U.S. and the rest of the world, respectively, for 1999, 2007, 2010, and 2015. Tables 5.1-2 and 5.1-4 display the estimates for the optimized scenarios for Europe and the U.S., respectively, for 2007, 2010, and 2015. Tables 5.1-6 and 5.1-7 provide the fuel and emissions savings due to CNS/ATM initiatives for Europe and U.S., respectively.

Table 5.1-10 highlights the percentage increase in emissions for the period 1999-2015 for the baseline and optimized scenarios. For example, CO_2 emissions are estimated to increase by 36%, 48.53%, and 34.23% for the U.S., Europe, and the rest of world, respectively, from 1999 to 2015 with no CNS/ATM measures. These estimates are lower than traffic growth per Table 5.1-9, because of non-CNS/ATM improvements such as increased fuel efficiency from improved aircraft engine designs or airport capacity increases from additional runways. However, CO_2 emissions are estimated to increase only by 28.68% and 41.53% for the U.S. and Europe, respectively, if the planned CNS/ATM measures are implemented with traffic growths of 51.8% and 63.4% from 1999 to 2015. The traffic growth for all scenarios is based on the FESG forecast.

[?]Table 5.1-1. Detailed Results for Europe (Baseline in Metric Tons)

		Fuel			HC			CO			NO_x			CO_2		
Year	**Mode**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**
1999	**Total**	**93,300**	**105,700**	**128,100**	**174**	**189**	**216**	**798**	**914**	**1,107**	**1,290**	**1,458**	**1,761**	**293,900**	**332,900**	**403,500**
	Cruise	76,100	87,400	105,500	148	163	188	631	740	913	1,085	1,240	1,487	239,700	275,300	332,300
	Below 3000'	11,800	12,900	17,200	4	4	6	31	38	58	184	197	253	37,200	40,600	54,200
	Surface	5,400	5,400	5,400	22	22	22	136	136	136	21	21	21	17,000	17,000	17,000
2007	**Total**	**118,000**	**133,100**	**160,500**	**217**	**235**	**268**	**1,003**	**1,143**	**1,381**	**1,611**	**1,816**	**2,187**	**371,800**	**419,400**	**505,600**
	Cruise	93,200	107,000	129,100	182	199	230	773	905	1,118	1,328	1,518	1,820	293,600	337,100	406,700
	Below 3000'	17,700	19,000	24,300	6	7	9	50	58	83	255	270	339	55,800	59,900	76,500
	Surface	7,100	7,100	7,100	29	29	29	180	180	180	28	28	28	22,400	22,400	22,400
2010	**Total**	**125,700**	**141,600**	**170,200**	**230**	**249**	**283**	**1,066**	**1,214**	**1,462**	**1,704**	**1,919**	**2,308**	**396,000**	**446,000**	**536,200**
	Cruise	97,700	112,200	135,300	191	209	241	810	949	1,172	1,392	1,592	1,909	307,800	353,400	426,200
	Below 3000'	20,100	21,500	27,000	7	8	10	58	67	92	281	296	368	63,300	67,700	85,100
	Surface	7,900	7,900	7,900	32	32	32	198	198	198	31	31	31	24,900	24,900	24,900
2015	**Total**	**140,000**	**157,000**	**187,600**	**253**	**273**	**310**	**1,185**	**1,343**	**1,609**	**1,866**	**2,095**	**2,511**	**441,100**	**494,600**	**591,000**
	Cruise	104,500	120,000	144,700	204	223	258	866	1,015	1,253	1,489	1,702	2,041	329,200	378,000	455,800
	Below 3000'	25,800	27,300	33,200	10	11	13	77	86	114	339	355	432	81,300	86,000	104,600
	Surface	9,700	9,700	9,700	39	39	39	242	242	242	38	38	38	30,600	30,600	30,600

Table 5.1-2. Detailed Results for Europe (Optimized in Metric Tons)

		Fuel			HC			CO			NO_x			CO_2		
Year	**Mode**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**
2007	**Total**	**111,600**	**128,300**	**152,600**	**194**	**217**	**243**	**907**	**1,055**	**1,236**	**1,493**	**1,715**	**2,044**	**351,600**	**404,200**	**480,700**
	Cruise	87,200	102,500	121,500	159	181	206	679	819	975	1,214	1,421	1,681	274,700	322,900	382,700
	Below 3000'	17,300	18,700	24,000	6	7	8	49	57	82	251	266	335	54,500	58,900	75,600
	Surface	7,100	7,100	7,100	29	29	29	179	179	179	28	28	28	22,400	22,400	22,400
2010	**Total**	**119,500**	**135,900**	**161,200**	**202**	**222**	**246**	**934**	**1,079**	**1,256**	**1,561**	**1,775**	**2,110**	**376,400**	**428,100**	**507,800**
	Cruise	92,300	107,300	127,100	163	182	205	684	820	971	1,257	1,455	1,718	290,700	338,000	400,400
	Below 3000'	19,400	20,800	26,300	7	8	9	55	64	90	274	290	362	61,100	65,500	82,800
	Surface	7,800	7,800	7,800	32	32	32	195	195	195	30	30	30	24,600	24,600	24,600
2015	**Total**	**131,500**	**149,600**	**176,400**	**217**	**240**	**268**	**1,025**	**1,182**	**1,372**	**1,690**	**1,925**	**2,284**	**414,200**	**471,200**	**555,600**
	Cruise	98,100	114,700	135,600	169	192	218	719	867	1,029	1,331	1,549	1,831	309,000	361,300	427,100
	Below 3000'	24,000	25,500	31,400	10	10	12	71	80	108	322	339	416	75,600	80,300	98,900
	Surface	9,400	9,400	9,400	38	38	38	235	235	235	37	37	37	29,600	29,600	29,600

[?] Data in shaded columns are preliminary

[?]Table 5.1-3. Detailed Results for CONUS (Baseline in Metric Tons)

		Fuel			HC			CO			NO_x			CO_2		
Year	**Mode**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**
1999	**Total**	**126,000**	**146,100**	**177,100**	**301**	**349**	**416**	**1,742**	**2,116**	**2,571**	**1,576**	**1,820**	**2,191**	**396,900**	**460,200**	**557,800**
	Cruise	101,500	119,900	146,100	254	301	365	1,447	1,794	2,171	1,292	1,521	1,848	319,700	377,700	460,200
	Below 3000'	16,400	18,100	22,900	7	8	11	78	105	183	255	270	314	51,700	57,000	72,100
	Surface	8,100	8,100	8,100	40	40	40	217	217	217	29	29	29	25,500	25,500	25,500
2007	**Total**	**151,400**	**175,200**	**211,700**	**364**	**420**	**499**	**2,094**	**2,538**	**3,075**	**1,876**	**2,165**	**2,603**	**476,900**	**551,900**	**666,800**
	Cruise	119,900	141,700	172,600	301	356	431	1,709	2,120	2,565	1,526	1,797	2,183	377,700	446,400	543,700
	Below 3000'	20,700	22,700	28,300	9	10	14	97	130	222	311	329	381	65,200	71,500	89,100
	Surface	10,800	10,800	10,800	54	54	54	288	288	288	39	39	39	34,000	34,000	34,000
2010	**Total**	**160,400**	**185,000**	**223,000**	**385**	**443**	**526**	**2,220**	**2,678**	**3,236**	**1,966**	**2,264**	**2,719**	**505,300**	**582,800**	**702,600**
	Cruise	124,300	146,900	179,000	312	369	447	1,773	2,198	2,660	1,583	1,863	2,264	391,500	462,700	563,900
	Below 3000'	23,100	25,100	31,000	10	11	16	108	141	237	336	354	408	72,800	79,100	97,700
	Surface	13,000	13,000	13,000	63	63	63	339	339	339	47	47	47	41,000	41,000	41,000
2015	**Total**	**173,100**	**198,700**	**238,000**	**424**	**485**	**570**	**2,414**	**2,890**	**3,470**	**2,076**	**2,386**	**2,859**	**545,200**	**625,900**	**749,700**
	Cruise	129,200	152,600	185,900	324	384	464	1,841	2,283	2,763	1,644	1,935	2,352	407,000	480,700	585,600
	Below 3000'	26,300	28,500	34,500	12	13	18	122	156	256	368	387	443	82,800	89,800	108,700
	Surface	17,600	17,600	17,600	88	88	88	451	451	451	64	64	64	55,400	55,400	55,400

Table 5.1-4. Detailed Results for CONUS (Optimized in Metric Tons)

		Fuel			HC			CO			NO_x			CO_2		
Year	**Mode**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**	**Low**	**Median**	**High**
2007	**Total**	**145,600**	**168,300**	**204,100**	**331**	**378**	**441**	**1,911**	**2,318**	**2,804**	**1,776**	**2,043**	**2,471**	**458,600**	**530,100**	**642,900**
	Cruise	115,000	135,700	165,900	272	317	376	1,539	1,914	2,308	1,430	1,679	2,055	362,300	427,500	522,600
	Below 3000'	20,300	22,300	27,900	8	10	14	96	128	220	308	326	378	63,900	70,200	87,900
	Surface	10,300	10,300	10,300	51	51	51	276	276	276	38	38	38	32,400	32,400	32,400
2010	**Total**	**153,600**	**176,400**	**213,200**	**332**	**381**	**437**	**1,960**	**2,380**	**2,863**	**1,832**	**2,095**	**2,520**	**483,800**	**555,600**	**671,600**
	Cruise	119,300	140,100	171,000	264	311	363	1,539	1,926	2,313	1,459	1,704	2,075	375,800	441,300	538,700
	Below 3000'	22,200	24,200	30,100	9	11	15	104	137	233	329	347	401	69,900	76,200	94,800
	Surface	12,100	12,100	12,100	59	59	59	317	317	317	44	44	44	38,100	38,100	38,100
2015	**Total**	**164,800**	**188,000**	**225,600**	**370**	**415**	**476**	**2,128**	**2,556**	**3,061**	**1,931**	**2,199**	**2,641**	**519,100**	**592,300**	**710,700**
	Cruise	124,200	145,300	176,800	280	324	380	1,607	2,000	2,406	1,517	1,767	2,153	391,200	457,700	556,900
	Below 3000'	24,900	27,000	33,100	11	12	17	115	150	249	357	375	431	78,400	85,100	104,300
	Surface	15,700	15,700	15,700	79	79	79	406	406	406	57	57	57	49,500	49,500	49,500

[??] Data in shaded columns are preliminary

Table 5.1-5. Detailed Results for Global Remainder (Baseline in Metric Tons)

		Fuel			HC			CO			NO_x			CO_2		
Year	Mode	Low	Median	High	Low	Median	High	Low	Median	High	Low	Median	High	Low	Median	High
1999	**Total**	**150,700**	**181,300**	**234,500**	**277**	**334**	**413**	**1,011**	**1,201**	**1,475**	**2,272**	**2,737**	**3,584**	**474,700**	**571,100**	**738,700**
	Cruise	129,400	160,000	213,200	227	284	363	745	935	1,209	2,013	2,478	3,325	407,600	504,000	671,600
	Below 3000'	12,300	12,300	12,300	3	3	3	31	31	31	223	223	223	38,700	38,700	38,700
	Surface	9,000	9,000	9,000	47	47	47	235	235	235	36	36	36	28,400	28,400	28,400
2007	**Total**	**183,100**	**220,500**	**285,300**	**337**	**406**	**502**	**1,223**	**1,454**	**1,788**	**2,762**	**3,330**	**4,362**	**576,800**	**694,600**	**898,700**
	Cruise	157,800	195,200	260,000	277	346	442	909	1,140	1,474	2,455	3,023	4,055	497,100	614,900	819,000
	Below 3000'	14,600	14,600	14,600	4	4	4	36	36	36	264	264	264	46,000	46,000	46,000
	Surface	10,700	10,700	10,700	56	56	56	278	278	278	43	43	43	33,700	33,700	33,700
2010	**Total**	**191,300**	**230,400**	**298,200**	**352**	**424**	**525**	**1,277**	**1,519**	**1,868**	**2,886**	**3,481**	**4,561**	**602,700**	**725,800**	**939,400**
	Cruise	165,100	204,200	272,000	290	362	463	951	1,193	1,542	2,568	3,163	4,243	520,100	643,200	856,800
	Below 3000'	15,100	15,100	15,100	4	4	4	38	38	38	274	274	274	47,600	47,600	47,600
	Surface	11,100	11,100	11,100	58	58	58	288	288	288	44	44	44	35,000	35,000	35,000
2015	**Total**	**202,000**	**243,400**	**315,200**	**371**	**447**	**554**	**1,345**	**1,601**	**1,971**	**3,049**	**3,678**	**4,822**	**636,300**	**766,700**	**992,900**
	Cruise	174,800	216,200	288,000	307	383	490	1,007	1,263	1,633	2,719	3,348	4,492	550,600	681,000	907,200
	Below 3000'	15,700	15,700	15,700	4	4	4	39	39	39	284	284	284	49,500	49,500	49,500
	Surface	11,500	11,500	11,500	60	60	60	299	299	299	46	46	46	36,200	36,200	36,200

[?]Table 5.1-6. Fuel and Emissions Savings for Europe (Metric Tons)

Median		Baseline					CNS/ATM Improvements									
Year	Mode	Fuel	HC	CO	NOx	CO_2	Fuel		HC		CO		NOx		CO_2	
1999	**Total**	**105,700**	**189**	**914**	**1,458**	**332,900**										
	Cruise	87,400	163	740	1,240	275,300										
	Below 3000	12,900	4	38	197	40,600										
	Surface	5,400	22	136	21	17,000										
2007	**Total**	**133,100**	**235**	**1,143**	**1,816**	**419,400**	**128,300**	**-3.6%**	**217**	**-7.7%**	**1,055**	**-7.7%**	**1,715**	**-5.6%**	**404,200**	**-3.6%**
	Cruise	107,000	199	905	1,518	337,100	102,500		181		819		1,421		322,900	
	Below 3000	19,000	7	58	270	59,900	18,700		7		57		266		58,900	
	Surface	7,100	29	180	28	22,400	7,100		29		179		28		22,400	
2010	**Total**	**141,600**	**249**	**1,214**	**1,919**	**446,000**	**135,900**	**-4.0%**	**222**	**-10.8%**	**1,079**	**-11.1%**	**1,775**	**-7.5%**	**428,100**	**-4.0%**
	Cruise	112,200	209	949	1,592	353,400	107,300		182		820		1,455		338,000	
	Below 3000	21,500	8	67	296	67,700	20,800		8		64		290		65,500	
	Surface	7,900	32	198	31	24,900	7,800		32		195		30		24,600	
2015	**Total**	**157,000**	**273**	**1,343**	**2,095**	**494,600**	**149,600**	**-4.7%**	**240**	**-12.1%**	**1,182**	**-12.0%**	**1,925**	**-8.1%**	**471,200**	**-4.7%**
	Cruise	120,000	223	1,015	1,702	378,000	114,700		192		867		1,549		361,300	
	Below 3000	27,300	11	86	355	86,000	25,500		10		80		339		80,300	
	Surface	9,700	39	242	38	30,600	9,400		38		235		37		29,600	

[?] Data in shaded columns are preliminary

Table 5.1-7. Fuel and Emissions Savings for CONUS (Metric Tons)

Median		Baseline					CNS/ATM Improvements									
Year	Mode	Fuel	HC	CO	NOx	CO_2	Fuel		HC		CO		NOx		CO_2	
1999	**Total**	**146,100**	**349**	**2,116**	**1,820**	**460,200**										
	Cruise	119,900	301	1,794	1,521	377,700										
	Below 3000	18,100	8	105	270	57,000										
	Surface	8,100	40	217	29	25,500										
2007	**Total**	**175,200**	**420**	**2,538**	**2,165**	**551,900**	**168,300**	**-3.9%**	**378**	**-10.0%**	**2,318**	**-8.7%**	**2,043**	**-5.6%**	**530,100**	**-3.9%**
	Cruise	141,700	356	2,120	1,797	446,400	135,700		317		1,914		1,679		427,500	
	Below 3000	22,700	10	130	329	71,500	22,300		10		128		326		70,200	
	Surface	10,800	54	288	39	34,000	10,300		51		276		38		32,400	
2010	**Total**	**185,000**	**443**	**2,678**	**2,264**	**582,800**	**176,400**	**-4.6%**	**381**	**-14.0%**	**2,380**	**-11.1%**	**2,095**	**-7.5%**	**555,600**	**-4.6%**
	Cruise	146,900	369	2,198	1,863	462,700	140,100		311		1,926		1,704		441,300	
	Below 3000	25,100	11	141	354	79,100	24,200		11		137		347		76,200	
	Surface	13,000	63	339	47	41,000	12,100		59		317		44		38,100	
2015	**Total**	**198,700**	**485**	**2,890**	**2,386**	**625,900**	**188,000**	**-5.4%**	**415**	**-14.4%**	**2,556**	**-11.6%**	**2,199**	**-7.8%**	**592,300**	**-5.4%**
	Cruise	152,600	384	2,283	1,935	480,700	145,300		324		2,000		1,767		457,700	
	Below 3000	28,500	13	156	387	89,800	27,000		12		150		375		85,100	
	Surface	17,600	88	451	64	55,400	15,700		79		406		57		49,500	

Table 5.1-8. Summary Results for Global Remainder (Metric Tons)

Median		Baseline					CNS/ATM Improvements									
Year	Mode	Fuel	HC	CO	NOx	CO_2	Fuel		HC		CO		NOx		CO_2	
1999	**Total**	**181,300**	**334**	**1,201**	**2,737**	**571,100**										
	Cruise	160,000	284	935	2,478	504,000										
	Below 3000	12,300	3	31	223	38,700										
	Surface	9,000	47	235	36	28,400										
2007	**Total**	**220,500**	**406**	**1,454**	**3,330**	**694,600**	**-**		**-**		**-**		**-**		**-**	
	Cruise	195,200	346	1,140	3,023	614,900	-		-		-		-		-	
	Below 3000	14,600	4	36	264	46,000	-		-		-		-		-	
	Surface	10,700	56	278	43	33,700	-		-		-		-		-	
2010	**Total**	**230,400**	**424**	**1,519**	**3,481**	**725,800**	**-**		**-**		**-**		**-**		**-**	
	Cruise	204,200	362	1,193	3,163	643,200	-		-		-		-		-	
	Below 3000	15,100	4	38	274	47,600	-		-		-		-		-	
	Surface	11,100	58	288	44	35,000	-		-		-		-		-	
2015	**Total**	**243,400**	**447**	**1,601**	**3,678**	**766,700**	**-**		**-**		**-**		**-**		**-**	
	Cruise	216,200	383	1,263	3,348	681,000	-		-		-		-		-	
	Below 3000	15,700	4	39	284	49,500	-		-		-		-		-	
	Surface	11,500	60	299	46	36,200	-		-		-		-		-	

Table 5.1-9. Regional Demand and Growth Rate Using FESG Forecast

Flights in Parametric Model				
Region/Year	1999	2007	2010	2015
CONUS	59,232	76,128	81,635	89,907
EUROPE	23,821	31,687	34,348	38,912
GLOBAL	29,870	39,600	42,825	48,036
Growth Rate relative to 1999 (FESG Data)				
CONUS	0%	29%	38%	52%
EUROPE	0%	33%	44%	63%
GLOBAL	0%	33%	43%	61%

Table 5.1-10. Percent of Increase from 1999 to 2015

U.S.	CO2	HC	CO	NOx
Baseline	36.00%	40.28%	37.10%	31.14%
Optimized	28.68%	20.00%	21.23%	20.92%
Europe	**CO2**	**HC**	**CO**	**NOx**
Baseline	48.53%	44.27%	47.33%	43.76%
Optimized	41.53%	27.08%	29.77%	32.03%

5.1.1 Sensitivity Analysis Example

The parametric model allows the performance of a sensitivity analyses. This subsection provides an example of such an analysis.

Table 5.1.1-1 displays an example of a parametric variation. In this example, we modified the unimpeded taxi time improvements due to technology changes. The default improvement for the optimized cases is 2.5% during the period 2007-2015. To highlight the variation, we changed the improvement to 5% in 2010 and 10% in 2015. Table 5.1-1 displays the results for the surface portion only. This variation results in 8.5% fuel savings in 2010 and 14.2% in 2015, versus the original 7.2% and 10.9%. All results are relative to the baseline without improvements.

[?]**Table 5.1.1-1. Example of Parametric Variation - Modify Unimpeded Taxi Times**

Example of Parametric Variation - Modify Unimpeded Taxi Times (Metric Tons)																
Median		Baseline					CNS/ATM Improvements									
Year	Mode	Fuel	HC	CO	NOx	CO_2	Fuel		HC		CO		NOx		CO_2	
2010	Total Taxi	13,000	71	354	47	40,950	12,060	-7.2%	66	-7.0%	331	-6.5%	44	-6.4%	37,990	-7.2%
		With 5% reduction in Unimpeded Taxi Times					11,900	-8.5%	65	-8.5%	325	-8.2%	43	-8.5%	37,485	-8.5%
2015	Total Taxi	17,600	99	473	64	55,440	15,684	-10.9%	88	-11.1%	425	-10.1%	57	-10.9%	49,405	-10.9%
		With 10% reduction in Unimpeded Taxi Times					15,100	-14.2%	85	-14.1%	408	-13.7%	55	-14.1%	47,565	-14.2%

[?] Data in shaded columns are preliminary

5.2 European Simulation Results

Table 5.2-1 gives the results, computed with the AEM model developed by the EUROCONTROL Experimental Centre Business Unit Environment, for the ECAC area based on CFMU traffic samples. The traffic volume (flights) represents normalised averages, based on the three traffic days under analysis and the historical traffic distribution for the baseline year 1999.

Table 5.2-1. European Simulations (EUROCONTROL)

EEC	1999	2005	2010	2015
Flights	22,175	29,271	35,083	40,707
Fuel (tons)	99,218	125,987	144,356	155,744
CO_2 (tons)	312,145	396,734	454,577	490,438

Figure 5.2-1 shows the traffic evolution from the baseline year 1999 until 2015. This traffic growth is based on STATFOR forecast. The daily traffic forecasted increases from the baseline year 1999 in a slightly sub linear fashion, but close to linear way, until 2015 where there is an almost doubling (83.57% increase) of traffic volume during this period.

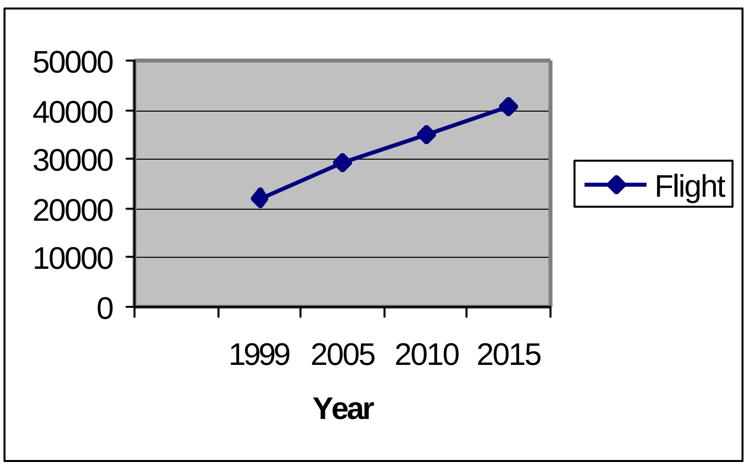

Figure5.2-1. EEC Traffic Evolution

Figure 5.2-2 below shows the estimated evolution of fuel consumption through air traffic, based on the analysed traffic samples. The estimated fuel consumption evolves in a manner similar to the forecasted yearly traffic per day, in a slightly sub linear fashion. Where the traffic volume in 2015 is almost twice the volume of 1999, the fuel consumption increases by about 57%.

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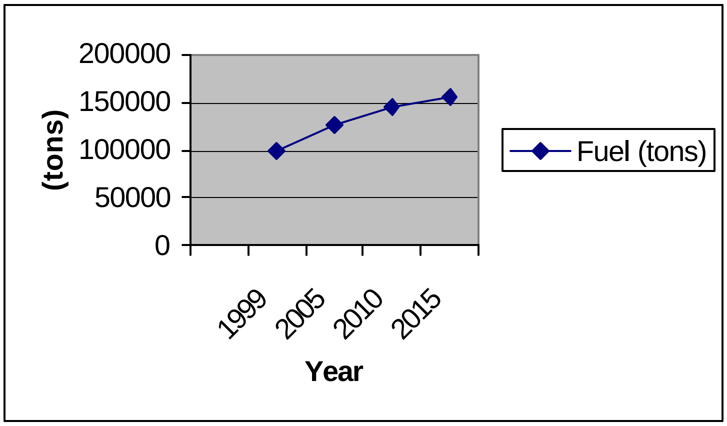


Figure 5.2-2. EEC Fuel Burn Estimation

Figure 5.2-3 shows the estimated emissions for CO_2 through air traffic, based on the analysed traffic samples. The CO_2 emissions follow the trend observed for the fuel consumption. CO_2 emissions estimated for 2015 are about 57% higher than for 1999.

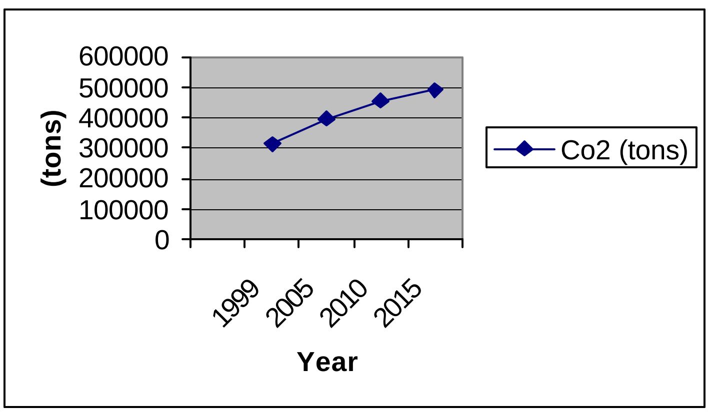


Figure 5.2-3. EEC CO_2 Emission Estimation

5.2.1 Interpretation

Fuel burn and CO_2 emissions are growing less quickly than traffic (57% increase of fuel burn and CO_2 emissions compared to the 84% increase of the traffic volume), because of the introduction of more efficient engine technology due to aircraft retirement and fleet expansion.

About 55% of the flights appearing in the traffic samples for 2015 use newer aircraft replacing older aircraft (older than 26 years) and earlier. Those aircraft profit from a fuel and emission efficiency increase due to technology progress of roughly about 1% per year. A rough, parametric estimation combining the 55% aircraft type replacement information with roughly estimated 26%

fuel efficiency increase applied to a 84% increased traffic sample would lead to a fuel consumption increase of 56 %. This correlates almost perfectly (56 versus 57 %) with the figures produced by the detailed EUROCONTROL Experimental Centre Business Unit Environment modeling approach and confirms the quality of those results.

5.3 Comparison of Results

The comparison and cross-validation of the European simulations and the parametric model is under way by both organisations. Note that the simulation and parametric model results contained in this document cannot be compared directly because of differences in certain key assumptions. For example, the parametric model uses the FESG growth rate where the simulation uses the STATFOR growth rate. Thus, comparing the results requires reviewing the assumptions and the inputs in detail and making necessary adjustments.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Future Work

It is recommended that future work should cover the following activities:

?? Continue validation and evolution of modeling capability.
?? Perform additional simulations for specific regions to better understand the impact of particular CNS/ATM measures.
?? Using parametric approach, develop estimate for 1990 (Kyoto reference date)
?? Refine emission calculation, especially for NO_x

The parametric model estimates the current and future global fuel burn and emissions. This model further estimates current and future savings due to CNS/ATM measures for the U.S. and Europe. Furthermore, it also can be used to perform sensitivity analyses. However, in order to improve the estimates and include the impact of CNS/ATM initiatives on other regions of the world, the following items still need to be completed.

?? CNS/ATM initiatives, NAS architecture and ATM 2000+ are evolving in the U.S. and Europe and need to be revisited periodically. As time passes, we will understand better how they will contribute to flight efficiencies.

?? Gather information on CNS/ATM initiatives in other regions of the world and add it to the parametric model.

?? Perform additional simulations to provide the estimated impact of specific technology enhancements on flight efficiency that result in changes to fuel usage and emissions. A more detailed examination of the effect of altitude on the emissions and fuel usage should be performed.

?? In order to enhance our global estimates, we need to gather information on unscheduled flights, airport capacities, procedural differences, taxi times, future runway expansions and procedural changes and other operational factors. We need to enhance our knowledge of current and future airport capacities in the U.S. and Europe. For example, we only have capacity information for 80 airports in the U.S. This could be expanded to at least 100. For a given airport, when no capacity information exists, we assume that delays are negligible. This may not be true in reality. Similarly, in Europe we currently have limited information on capacities, unimpeded taxi-times and delays at various airports.

?? The parametric model should be enhanced, as new information becomes available. Various parameters need to be calibrated to represent different regions of the world better.

?? Cross validation of the two approaches needs to continue, including verification with operational flight data. This also would include a detailed review of the assumptions made in the two approaches and some sensitivity analyses of their effect on the results.

?? Enhance the user interface of the parametric model so any decision-maker can use it easily to perform sensitivity analyses. For example, one could change the forecast demand and compare the resulting fuel savings due to CNS/ATM initiatives. Likewise, one could change the schedule or the impact of one or several CNS/ATM initiatives and compare the resulting fuel savings. This is feasible to some extent currently, but definitely requires enhancement.

?? The FESG growth forecast is used in the parametric model in an aggregated form. One of the future enhancements should be to separate the FESG regional growth forecasts by aircraft type.

?? Growth rates should be predicted for routes (city pairs), in terms of passenger movements and then market intelligence applied to the trend in aircraft type/class likely to satisfy this demand.

?? Aircraft type plays a critical role in calculating fuel burn and emissions. Aircraft mapping, which is mapping of an unknown aircraft type to a known one, should be revisited and revised to reflect reality more accurately.

6.2 Summary

Tables 5.1-1 through 5.1-8 above provide a summary of annual fuel burn and emissions calculated using the parametric model for the baseline and enhanced scenarios for CONUS, Europe/ECAC and the rest of the world. They also highlight the percent savings due to CNS/ATM initiatives in the U.S. and European segments. Non-CNS/ATM initiatives such as fuel reductions due to increased engine efficiency and fleet mix changes are included in both baseline and optimized scenarios. The results for fuel savings and CO2 emissions also are depicted graphically in Figures 6.2-1 through 6.2-4 below.

Table 5.2-1 presents a summary of fuel burn and emissions for the baseline case calculated using simulations for Europe/ECAC.

A comparison of the baseline and enhanced scenarios using the parametric model for 2015, provided estimates of fuel savings from modernisation efforts in U.S. and Europe. In the U.S., daily fuel savings exceeded 10,000 metric tons/day or 5.4% of which 7,000 metric tons were due to more efficient trajectories, 1,500 tons were due to reductions in airborne delays at congested

airports, and 2,000 tons were due to reductions in surface delays, as well as more efficient taxiing.
Similarly, in Europe, daily fuel savings of 7,400 metric tons/day or 4.7% of which 5,300 metric tons were due to more efficient trajectories, 1,800 tons were due to reductions in airborne delays at congested airports, and 300 tons were due to reductions in surface delays.

Some of the parameters of the parametric model are estimated using the results of the CONUS simulation in FAA [1]. This simulation used actual flight trajectories. Other parameters, such as unimpeded taxi-times, demand, fleet mix, airport capacities and weather conditions are based on other data sources available in the FAA organisation (ASD-430) for the U.S., and data provided by EUROCONTROL for Europe. Furthermore, some of the parameters are calibrated to make them suitable for Europe. For example, flights generally are shorter in Europe compared to the U.S. Thus, fuel burn rates for the cruise portion (above 3,000 feet) may be different in Europe. Thus, while calculating the fuel burn rate (by aircraft type) statistics, i.e. median, low, and high, U.S. city pairs, less than 500 miles apart, are used. The parametric model uses a queueing model to estimate the changes in delay due to airport capacity or demand changes.

The parametric model allows one to perform sensitivity analyses; change the demand, growth factor; the impact of a CNS/ATM on airport capacity increase; and see how the change affects fuel usage and emissions.

This study has shown that cooperation between international organisations can provide results that neither group could have produced independently. This capability is the first step toward a quantifying the global emissions as well as evaluating the impact of CNS/ATM system on reducing fuel consumption and related emissions.

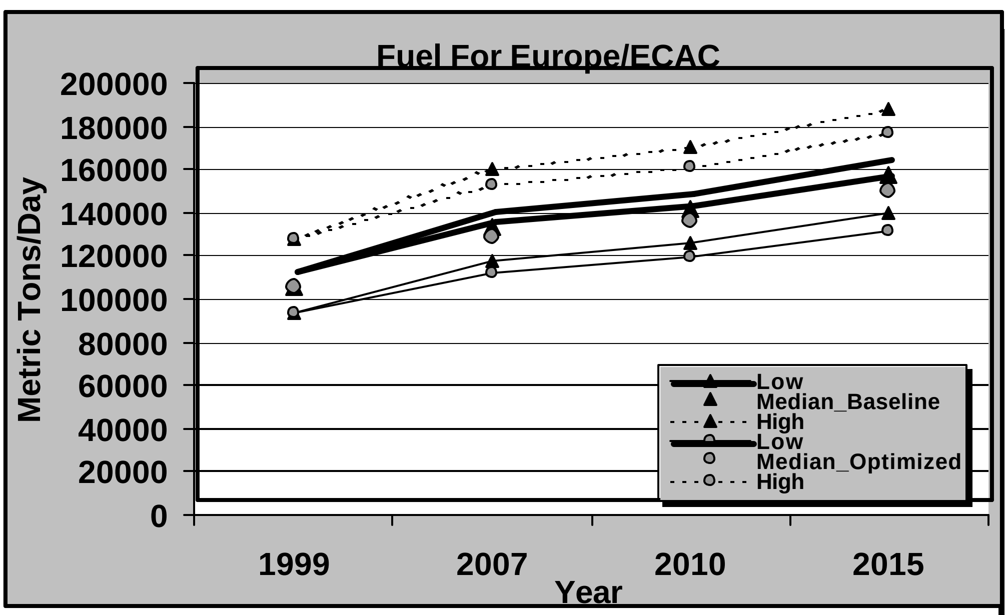


Figure 6.2-1. Fuel Usage Results for Europe

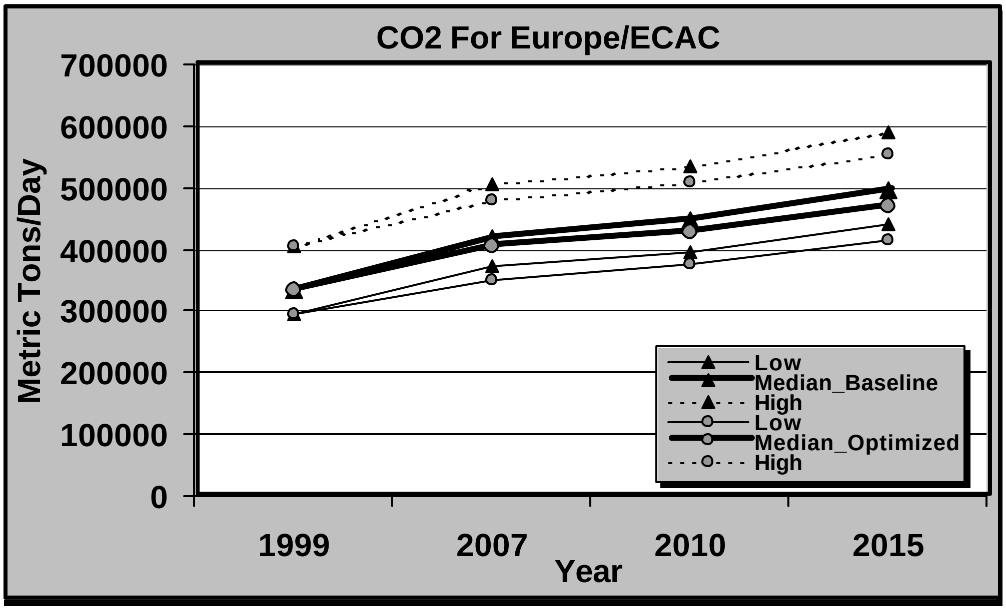


Figure 6.2-2. Carbon Dioxide Results for Europe

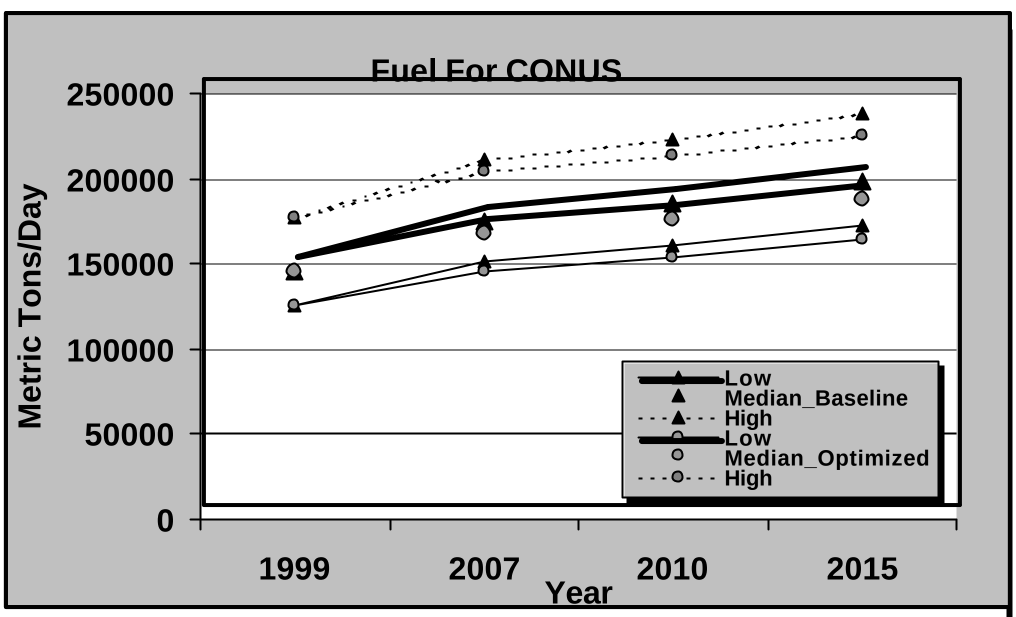


Figure 6.2-3. Fuel Usage for CONUS

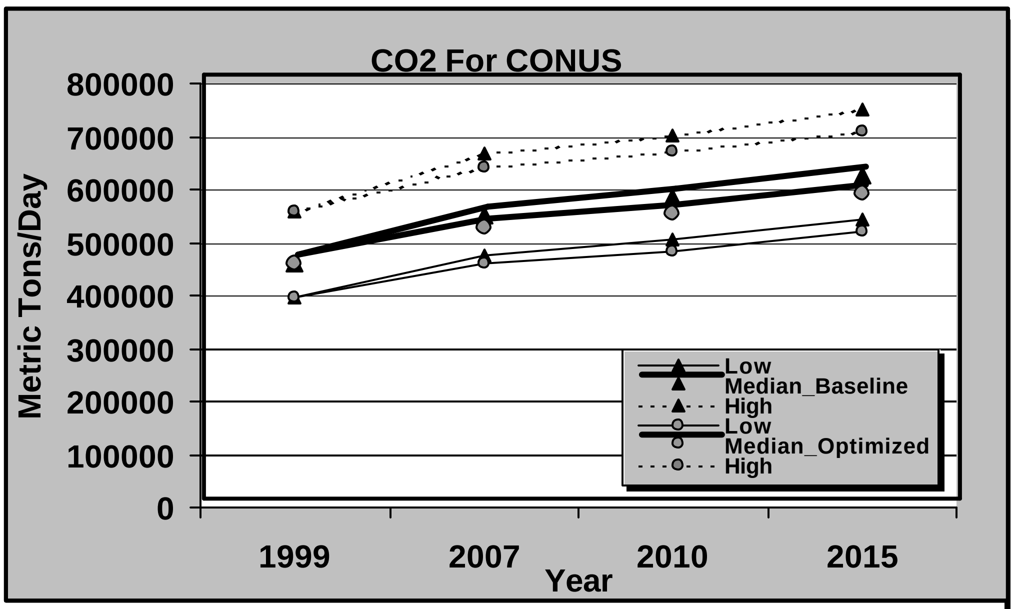


Figure 6.2-4. Carbon Dioxide Results for CONUS

7.0 LIST OF ACRONYMS

A

A/C	Aircraft
ADS-B/CDTI	Automatic Dependent Surveillance-Broadcast
AEA	Associations of European Airlines
AEM	Advanced Emission Model
AMOC	ATFM Modeling Capacity
APU	Auxiliary Power Unit
ATFM	Air Traffic Flow Management
ATA	Air Transport Associations

B

BADA	Base of Aircraft Data

C

CAEP	Committee on Aviation Environmental Protection
CFMU	EUROCONTROL Central Flow Management Unit
CNS/ATM	Communication, Navigation, Surveillance/Air Traffic Management
CONUS	Contiguous United States
CTAS	Center-TRACON Automation System

E

ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre
EUROCONTROL	European Organisation of the Safety of Air Navigation

F

FAA	Federal Aviation Administration
FESG	Forecast and Economics Sub Group

I

ICAO	International Civil Aviation Organisation
IFR	Instrumental Flight Rules
ITWS	Integrated Terminal Weather System

L

LTO	Landing and Take-Off (Cycle)

N

NAS	National Airspace System
NASPAC	National Airspace System Performance Capability
NCDC	National Climatic Data Center

O

OAG	Official Airline Guide

P

Piano	Fuel burn and emission model
PRM	Precision Runway Monitor

R

RVSM	Reduced Vertical Separation Minima

S

STATFOR	EUROCONTROL / Specialist Panel on Air Traffic Statistics and Forecasts

V

VFR	Visual Flight Rules

W

WAAS/LAAS	Wide Area/Local Area Augmentation
WG4	Working Group 4

8.0 BIBLIOGRAPHY/DATA SOURCES

1. The Impact of National Airspace System (NAS) Modernization on Aircraft Emissions, September 1998.
2. European Database of major airports in the ECAC states, 1997.
3. FESG fleet mix and flight forecast, 2000.
4. International Station Meteorological Climate Summary, Version 4.0, September 1996. Jointly produced by Fleet Numerical Meteorology and Oceanography Detachment, National Climatic Data Center, and USAFETAC OL-A.
5. VFR and IFR Capacity for 80 U.S. airports, FAA/ASD-400.
6. JP airline fleets international.
7. Avitas Inc.
8. World Fleet by Aircraft type/Generic class, Air Transport Association.
9. Enhanced Traffic Management System database.
10. Central Flow Management Unit databases.
11. Fuel per seat improvement over time, Presented at April '96 Virginia Beach Symposium "Global Atmospheric Effects of Aviation."
12. ICAO Engine Exhaust Emissions Data Bank, Doc. 9646-AN/943, First Edition, 1995.

    Database updated January 2000.
13. IPCC. Aviation and the Global Atmosphere 1999.
14. ICAO/CAEP Working Group 4, Emission Operation Working Group, "Global Airport Air Quality Best Practices," November 1999.
15. "European Airline Delays in 1999." Association of European Airline.
16. **http://www.faa.gov/nasarchitecture/version4.htm**
17. Donald Gross, Carl M. Harris, *Fundamentals of Queueing Theory*, Third Edition. Wiley, New York, 1998.
18. BADA, Base of Aircraft Data, EUROCONTROL Experimental Centre **http://www.eurocontrol.fr/projects/bada**
19. 1999 Airbus Global Market Forecast " report (Airbus GMF, App. F)
20. IATA Environmental Report 1996, p41, Source Rolls-Royce PLC, April 96
21. (http://books.nap.edu/books/0309047323/html figure 2.9/) (National Research Council Report)
22. AEROTRACE Programme, Cottington et al., 1997

9.0 DEFINITIONS

Approach: Final approach at destination airport below 3,000 feet

Arrival Delay: A difference of more than 15 minutes between scheduled arrival time and actual arrival time. This definition applies to the Association of European Airlines (AEA) tables

Baseline Scenario: The simulation scenario without CNS/ATM measures. However, non-CNS/ATM enhancements such as additional runways, aircraft engine improvements, or fleet mix changes are included.

Climb: Initial climb below 3,000 feet

Cruise: Portion of flight above 3,000 feet

Delay at Arrival Airport (Approach Delay): Air holds in the "last tier" due to congestion at the destination airports.

Departure Delay (Gate Delay): A difference of more than 15 minutes between scheduled departure time and actual departure time. This definition applies to the Association of European Airlines (AEA) tables.

Measurement Units: Fuel and emissions are in metric tons, altitudes are in feet, and distances are in nautical miles unless otherwise specified.

Optimal Scenario: The simulation scenario with CNS/ATM measures. Non-CNS/ATM improvements such as additional runways, aircraft engine improvements or fleet mix changes are also included.

Surface: Portion of flight that occurs on the ground, i.e., taxi-in and taxi-out

Take-Off: Portion of flight that starts from aircraft rolling down the runway and ends at Climb.

Unimpeded Approach: Final approach without delay, i.e. holding in the air

Unimpeded Idle Time: Sum of unimpeded taxi-out and unimpeded taxi-in times

Unimpeded Taxi-In: Average taxi-in time without delay

Unimpeded Taxi-Out: Average taxi-out time without delay

APPENDICES

APPENDIX A
EUROPEAN SIMULATION

A.1 TOOLS

AMOC

This tool was developed at the EUROCONTROL Experimental Centre to support large fast-time simulation studies for flow management research purposes. In the context of this study, it was used to produce 4D-flight profiles based on CFMU data.

AEM

During the work for this study a PC, dBase, Flight profile analysis tool, the Advanced Emission Model (AEM) was developed. It offers the possibility to analyze flight profiles for single flights or large air traffic data sets, to compute fuel burn and emission estimations for fuel, and CO, CO_2, NOx, SOx, HC, BEN, and H_2O.

The tool is still in prototype status and certain aspects under further validation. For that reason, EUROCONTROL has limited the publication of results only to fuel burn and CO_2 emissions. After further projected evolution and validation, AEM is planned for use in upcoming environmental studies performed by EUROCONTROL's Business Unit Environment. At a later state, a more user friendly and validated version of the tool may be available to other interested research bodies in the environmental context.

BADA

EUROCONTROL's base of aircraft data is one of the most reliable and used sources for aircraft performance and fuel flow data. It is based on original aircraft manufacturer information and largely used by the worldwide fast- and real-time simulation community. Detailed information is available on the EUROCONTROL Experimental Centre web site under **http://www.eurocontrol.fr/projects/bada**.

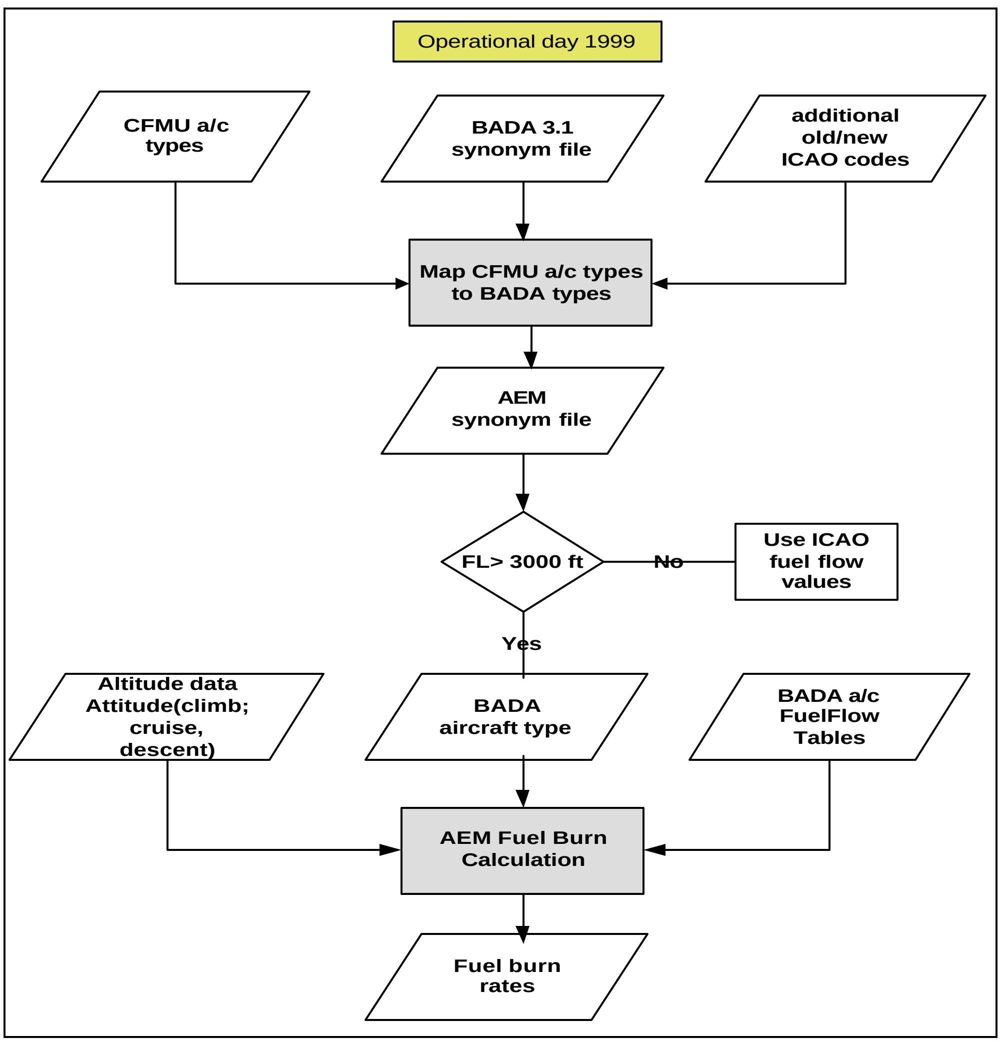
ICAO Engine Exhaust Emissions Data Bank

ICAO Engine Certification Data was used in analyzing the LTO part of the flight profiles contained in this study.

APPENDIX B
EUROPEAN SIMULATION
AIRCRAFT GROUPING AND REPRESENTATIVE AIRCRAFT FOR EMISSION AND FUEL BURN

B.1 FUEL FLOW AIRCRAFT ALLOCATION

For fuel burn calculation of our operational days, specific aircraft fuel flow data is needed. The fuel flow calculation is based on the EUROCONTROL BADA 3.1 fuel flow datasets (see Figure B.1-1). There is performance data for a list of aircraft models in BADA. Therefore, where the BADA 3.1 did not hold information for a specific aircraft that appears in our traffic sample, it is attached to a representative aircraft type known by BADA (see Table B.1-1).



.Figure B.1-1. Fuel Burn Calculation Steps

Table B.1-1. Aircraft Mapping for Fuel Burn Calculations

AC_TYPE	REF_AC	AC_TYPE	REF_AC	AC_TYPE	REF_AC	AC_TYPE	REF_AC
A300	A300	B73B	B73B	BE02	BE20	C160	C160
EA30	A300	B733	B73B	BE20	BE20	ND16	C160
A306	A300	AN72	B73B	C12	BE20	CL2T	C160
A30B	A300	B734	B73B	C20	BE20	CL44	C160
A3ST	A300	ZZZZ	B73B	C20A	BE20	HERN	C160
IL76	A300	B73F	B73F	BE10	BE20	DH7	C160
A310	A310	B735	B73B	BE18	BE20	DHC7	C160
EA31	A310	B73S	B73B	BE30	BE20	C421	C421
A319	A320	ZZZZ	B73B	BE3B	BE20	C414	C421
A320	A320	B73C	B73C	PC12	BE20	C441	C421
EA32	A320	B736	B73C	PC6	BE20	FA30	C421
A321	A320	B737	B73C	PC6T	BE20	STAR	C421
A330	A330	B738	B73C	PC7	BE20	P180	C421
EA33	A330	B73V	B73V	PUMA	BE20	BE60	C421
A340	A340	B74A	B74A	RANG	BE20	C550	C550
EA34	A340	B741	B74A	NA01	BE20	C500	C550
IL96	A340	B747	B747	AC6T	BE20	C501	C550
ATP	ATP	C5	B74A	AC6L	BE20	C525	C550
AT42	ATR	C17	B74A	AC70	BE20	C551	C550
ATR42	ATR	AN4R	B74A	AC80	BE20	C552	C550
AT43	ATR	A124	B74A	AC84	BE20	MU30	C550
AT44	ATR	B742	B74A	AC90	BE20	MU3	C550
AT45	ATR	B743	B74A	AC95	BE20	S601	C550
ATR72	ATR	B74B	B74B	SH5	BE20	S76	C550
AT72	ATR	B74S	B74B	GA7	BE20	HF20	C550
CN35	ATR	B74F	B74B	S330	BE20	SK60	C550
CV58	ATR	B744	B74B	AS30	BE20	BE40	C550
CVLT	ATR	B757	B757	S332	BE20	C560	C560
CS12	ATR	B752	B757	AS32	BE20	C56X	C560
B707	B707	B753	B757	H53	BE20	CARJ	CARJ
B701	B707	T204	B757	H47	BE20	J328	CARJ
B703	B707	B767	B767	H60	BE20	CL60	CL60
C135	B707	B762	B767	TUCA	BE20	L29A	CL60
KC10	B707	B763	B767	BE99	BE99	L29B	CL60
KC135	B707	B777	B777	BE90	BE99	GULF	CL60
K35R	B707	B772	B777	B350	BE99	G2	CL60
K35E	B707	B773	B777	BE9T	BE9L	G3	CL60
K35A	B707	BA11	BA11	BE9L	BE9L	G3	CL60
E3	B707	BA46	BA46	C21	BE9L	G5	CL60
IL62	B707	YK42	BA46	C130	C130	GLF2	CL60
VC10	B707			L382	C130	GLF3	CL60
WA42	B707			P3	C130	GLF4	CL60
B720	B707			P3C	C130	GFL5	CL60
NIM	B707			L188	C130	D228	D228
B727	B727			IL18	C130	E110	D228
B721	B727			AN12	C130	L410	D228
B722	B727			C121	C130	O410	D228
B73A	B73A			C2	C130	D328	D328
B731	B73A			DC6	C130	DC10	DC10
B732	B73A			BELF	C130		

Table B.1-1. Aircraft Mapping for Fuel Burn Calculations, Cont'd

AC_TYPE	REF_AC	AC_TYPE	REF_AC	AC_TYPE	REF_AC	AC_TYPE	REF_AC
DC8	DC8	GLF2	FA50	HS25	H25B	PA27	PA27
DC85	DC8	GLF3	FA50	H25B	H25B	PA23	PA27
DC86	DC8	G3	FA50	H25A	H25B	BE55	PA27
DC87	DC8	GLF4	FA50	H25C	H25B	BE56	PA27
IL86	DC8	G4	FA50	ATLA	H25B	BE58	PA27
C141	DC8	GLF5	FA50	WW24	H25B	PAZT	PA27
DC9	DC9	F406	FA50	JSTA	JSTA	AY22	PA27
C9	DC9	RA06	FA50	BA31	JSTA	G222	PA27
DHC8	DHC8	F900	FA50	JS31	JSTA	PN68	PA27
DH8	DHC8	DA90	FA50	JS20	JSTA	BE76	PA27
DH8C	DHC8	FGTR	FGTR	BA32	JSTA	AC11	PA27
DH8A	DHC8	TOR	FGTR	JS32	JSTA	AC14	PA27
DH8B	DHC8	MRC	FGTR	B190	JSTA	PA28	PA28
YK40	DHC8	F16	FGTR	JSTB	JSTB	PARO	PA28
E120	E120	JAGR	FGTR	JS41	JSTB	AA5	PA28
E121	E120	HAR	FGTR	BA41	JSTB	C150	PA28
E145	E120	HAWK	FGTR	L101	L101	C152	PA28
F27	F27	F1	FGTR	LJ35	LJ35	C172	PA28
FK27	F27	F4	FGTR	LR35	LJ35	C72R	PA28
AN24	F27	F5	FGTR	CL65	LJ35	M6	PA28
AN26	F27	F15	FGTR	C650	LJ35	MF17	PA28
AN30	F27	F18	FGTR	C750	LJ35	CE43	PA28
AN32	F27	F104	FGTR	LJ24	LJ35	GY80	PA28
N262	F27	MG21	FGTR	LR24	LJ35	BE19	PA28
FK28	F28	MG23	FGTR	LJ25	LJ35	BE23	PA28
F28	F28	MG25	FGTR	LR25	LJ35	BE24	PA28
FK50	F50	MG29	FGTR	LJ31	LJ35	BL17	PA28
F50	F50	CONC	FGTR	LR31	LJ35	SM26	PA28
FK60	F50	MRF1	FGTR	LJ36	LJ35	C177	PA28
F60	F50	MIR2	FGTR	LR35	LJ35	C77R	PA28
HS74	F50	MIR4	FGTR	LJ45	LJ35	C182	PA28
A748	F50	A10	FGTR	LR45	LJ35	C82R	PA28
FK70	F70	A4	FGTR	LJ55	LJ35	C185	PA28
F70	F70	A6	FGTR	LR55	LJ35	DH5	PA28
FK10	F100	A7	FGTR	LJ60	LJ35	DH6	PA28
F100	F100	F14	FGTR	LR60	LJ35	DHC6	PA28
F900	F900	VF14	FGTR	MD11	MD11	F260	PA28
FA10	FA10	SB32	FGTR	MD80	MD80	HELI	PA28
DA10	FA10	SB35	FGTR	MD90	MD80	L40	PA28
FA20	FA20	SB37	FGTR	MU2	MU2	OSCR	PA28
DA20	FA20	SB39	FGTR	MU20	MU2	P90R	PA28
ASTR	FA20	AJET	FGTR	P31T	P31T	S05R	PA28
F2TH	FA20	AMX	FGTR	PAY1	P31T	PA24	PA28
BJ40	FA20	AJ25	FGTR	PAY2	P31T	PA38	PA28
SBR1	FA20	MS76	FGTR	C425	P31T	Z42	PA28
P808	FA20	MC39	FGTR	G159	P31T	PA30	PA31
FA50	FA50	C101	FGTR	M339	FGTR	PA31	PA31
DA50	FA50	L39	FGTR	B2	FGTR		
		U2	FGTR				

Table B.1-1. Aircraft Mapping for Fuel Burn Calculations, Cont'd

AC_TYPE	REF_AC	AC_TYPE	REF_AC
PAT4	PA31	SH36	SH36
PA32	PA31	SH33	SH36
PA32R	PA31	SC7	SH36
P32R	PA31	AN28	SH36
PA32T	PA31	SW3	SW3
P32T	PA31	SW2	SW3
BE95	PA31	SW4	SW3
BN2T	PA31	ND26	SW3
BN2P	PA31	TU34	T134
BN2	PA31	T134	T134
TRIS	PA31	TU54	T154
C402	PA31	T154	T154
C404	PA31	TRIN	TRIN
C337	PA31	UH1	TRIN
C340	PA31	B12	TRIN
C355	PA31	S350	TRIN
C212	PA31	AS50	TRIN
D028	PA31	S355	TRIN
D28D	PA31	AS55	TRIN
C310	PA31	S350	TRIN
C303	PA31	AS50	TRIN
L200	PA31	AS65	TRIN
PA34	PA34	B222	TRIN
PASE	PA34	MBK7	TRIN
BE36	PA34	TAMP	TRIN
B36T	PA34	TBM7	TRIN
BE35	PA34	TOBA	TRIN
BE33	PA34	TB20	TRIN
DC3	PA34	RALL	TRIN
DR40	PA34	TB30	TRIN
DR44	PA34	TRIN	TRIN
R100	PA34	P28A	TRIN
R300	PA34	P28B	TRIN
C206	PA34	P28R	TRIN
C207	PA34	P28T	TRIN
C208	PA34	M20	TRIN
C210	PA34	M20P	TRIN
P210	PA34	M20T	TRIN
PA42	PA42	MO20	TRIN
PAY3	PA42	MO2K	TRIN
PAY4	PA42	MO22	TRIN
PAYE	PA42		
PA44	PA42		
PA46	PA42		
PA60	PA42		
AEST	PA42		
P66T	PA42		
P68	PA42		
AC50	PA42		
AC68	PA42		
SB20	SB20		
SF34	SF34		

Note: The abbreviations are ICAO abbreviations.

B.2 EMISSION CALCULATION

For the emission calculations, a whole flight is divided in three different parts.

- Below 3,000 feet (LTO Cycle)
- Between 3,000 feet and 9,000 Meters
- Above 9,000 Meters

Below 3,000 feet the calculation of emissions relies on the information provided by the "ICAO Engine Exhaust Emissions Data Bank," (Doc 96476-AN/943). This information holds the engine-mode and emission cross-reference file. For the aircraft type/engine type cross-reference, the FAA tables are used as a basis and are expanded to cover traffic sample.

Between 3,000 feet and 9,000 meters (~29,530 feet) the calculation of emissions relies on the information in the Boeing Two indices method emission table provided by the FAA. Table B.2-1 is prepared based on Figure B.2-1 below.

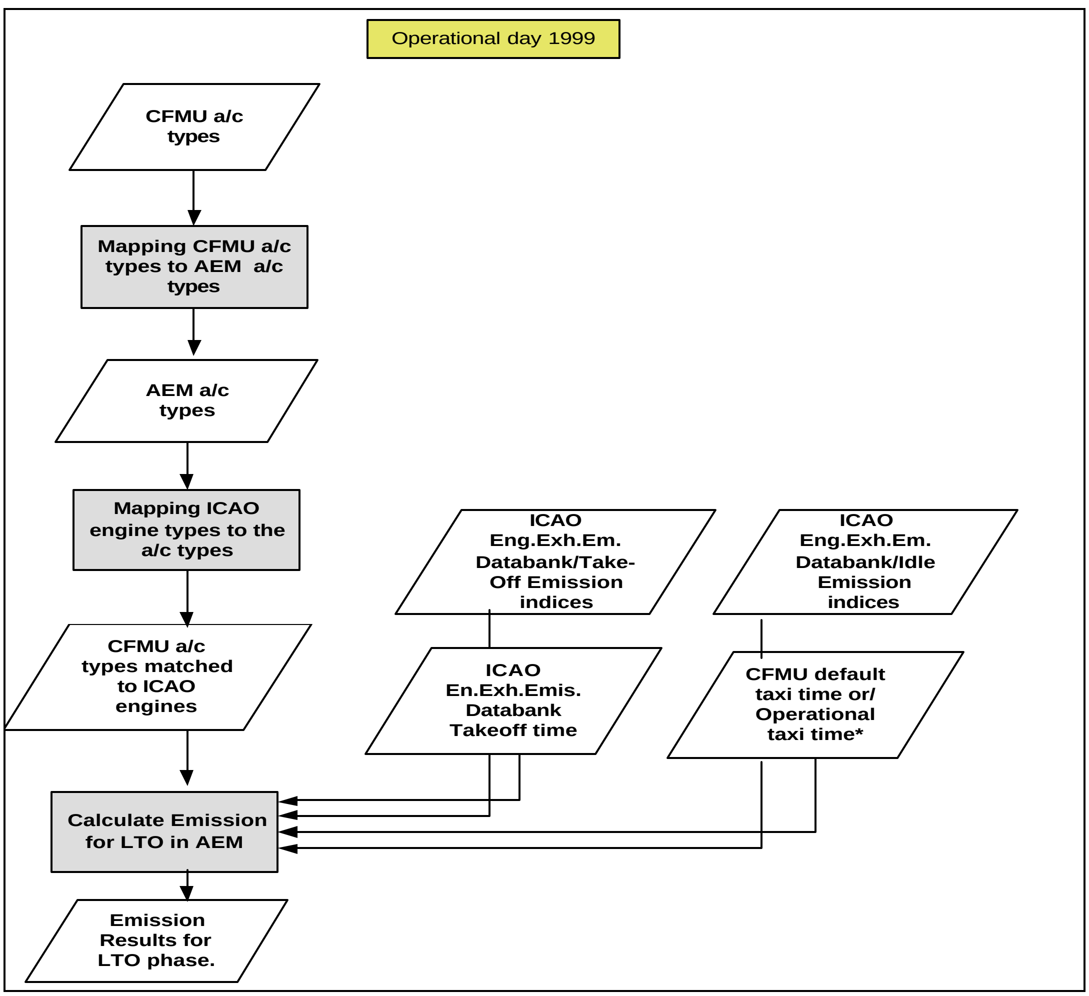


Figure B.2-1. Aircraft mapping for LTO emission calculation

B.3 TAXI DATA

The study applied individual taxi times to most flights, which were based on one representative values per city pair. The origin of the information was CFMU and/or several airlines (see Figure B-3). AEM uses airline data in case data from both sources was available. For city pair-aircraft type combinations, were no information was available, the following default values have been extracted as average values of the sources referenced below:

- **Taxi-in: 3.18 minutes (airline data average)**
- **Taxi-out: 7.11 minutes (CFMU data average)**

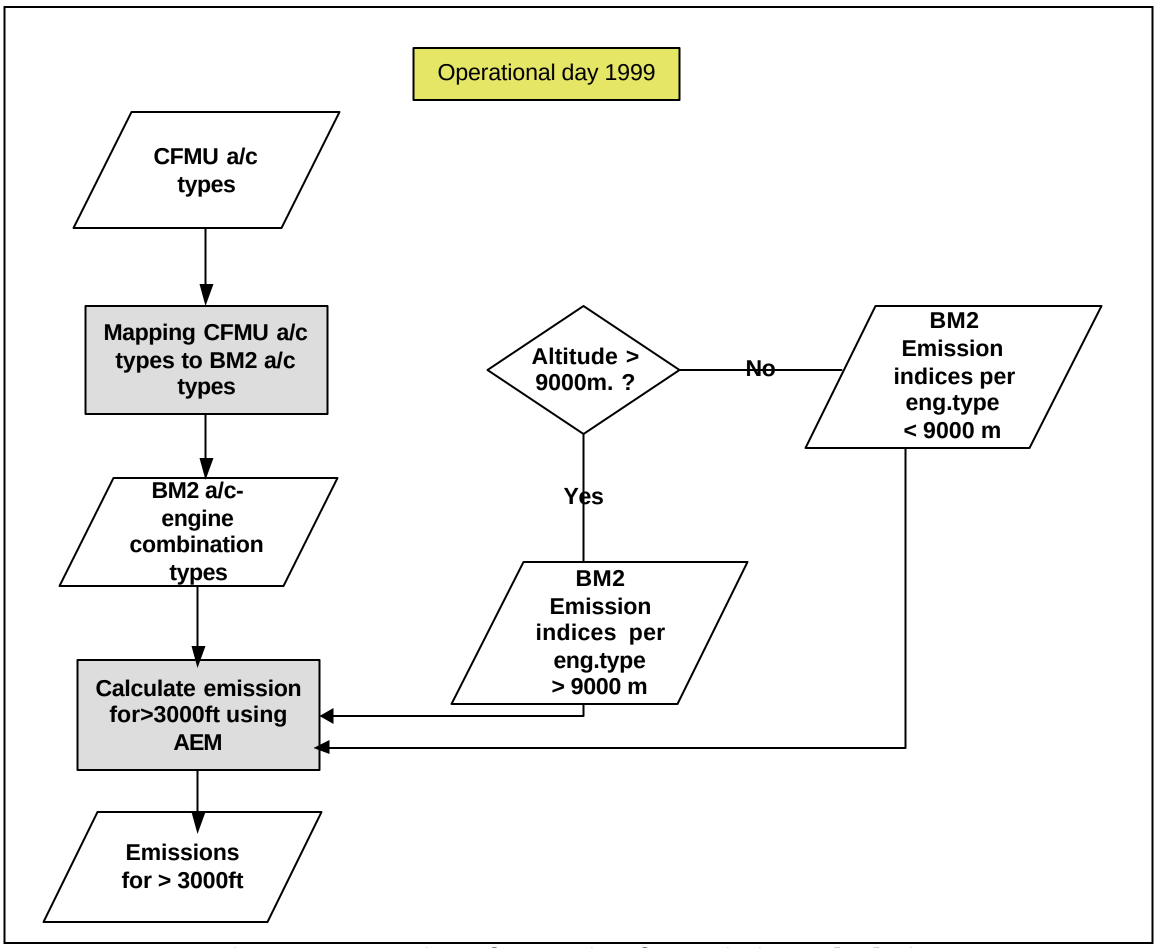


Figure B.2-2. Aircraft mapping for emission calculation

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
146-200	ALF502R-5	8.8	7.9	0.8	7.7	0.2	0.0
727-100	JT8D-7B	10.8	7.4	2.2	7.7	0.2	0.0
72S-200	JT8D-15	11.7	4.9	0.7	8.7	2.3	0.5
737-200	JT8D-15	10.8	5.4	0.8	7.7	3.3	0.7
73L-500	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
73Y-300	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
73Z-400	CFM56-3B	12.2	15.0	1.1	9.6	3.5	0.2
747-100	JT9D-7A	24.0	21.4	11.2	13.9	0.4	0.6
747-200B	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7
747-400	PW4056	21.2	3.6	0.3	14.2	0.3	0.3
757-200	RB211-535E4	20.7	11.5	1.1	10.3	2.9	0.1
767-200	CF6-80A	18.8	6.9	1.5	12.5	2.9	0.6
777-200	767 * 1.34	25.2	9.3	2.0	16.8	3.9	0.8
777-300	767 * 1.62	30.5	11.2	2.4	20.3	4.7	1.0
A10	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
A7	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
AA5	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
AC6T	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
AC6L	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
AC14	AC6T	8.1	4.0	0.2	8.1	4.0	0.2
AC50	AC6T	8.1	4.0	0.2	8.1	4.0	0.2
AC80	AC6T	8.1	4.0	0.2	8.1	4.0	0.2
AC84	AC6T	8.1	4.0	0.2	8.1	4.0	0.2
AEST	PA-60	8.1	4.0	0.2	8.1	4.0	0.2
A124	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7
A300	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
EA30	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A3ST	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A306	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A30B	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A30B2-100	CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A310	CF6-80A3	17.6	7.4	1.7	13.0	2.4	0.6
EA31	CF6-80A3	17.6	7.4	1.7	13.0	2.4	0.6
A31-200	CF6-80A3	17.6	7.4	1.7	13.0	2.4	0.6
A319	CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
A320	CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
EA32	CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
A321	CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
A32-200	CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
A330	1.28 * A300	27.1	22.6	9.0	19.4	1.4	1.1
EA33	MTOW	27.1	22.6	9.0	19.4	1.4	1.1
A340	1.53 * A300	32.4	27.0	10.8	23.2	1.7	1.1
EA34	MTOW	32.4	27.0	10.8	23.2	1.7	1.1
A748	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
HS74	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
AC11	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
AC6T	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
AC90	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
AC95	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
AJ25	FA10	10.7	5.6	0.5	8.7	1.3	0.4
AJET	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
AMX	LRJ	10.7	5.6	0.5	8.7	1.3	0.4

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
AN12	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
AN24	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
AN26	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
AN28	SH36	12.3	5.1	0.6	12.3	5.1	0.6
AN30	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
AN32	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
AN4R	B747	24.0	21.4	11.2	13.9	0.4	0.6
AN72	B737	11.4	12.9	0.8	9.4	3.8	0.2
AS50	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AS65	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
ASTR	FA10	10.7	5.6	0.5	8.7	1.3	0.4
ATLA	HS25	11.8	5.1	0.6	11.8	5.1	0.6
AT4	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AT42	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AT43	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AT44	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AT45	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AT72	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
ATR42	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
ATR72	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
ATP	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
AY22	C130	24.6	10.2	1.2	24.6	10.2	1.2
B2	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
B12	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
B36T	BE36	8.2	4.0	0.2	8.2	4.0	0.2
B190	LGTURB	13.1	4.3	0.0	13.1	4.3	0.0
B222	BE20	8.2	4.0	0.2	8.2	4.0	0.2
B350	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
B3C-320CH	JT3D-3B	15.1	38.8	44.3	5.9	7.7	7.7
B707	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
B701	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
B703	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
B720	B707	8.1	32.4	26.6	6.1	4.2	1.3
B721	JT8D-7B	10.8	7.4	2.2	7.7	0.2	0.0
B722	JT8D-15	11.7	4.9	0.7	8.7	2.3	0.5
B727	JT8D-7B	10.8	7.4	2.2	7.7	0.2	0.0
B731	B732	10.8	5.4	0.8	7.7	3.3	0.7
B732	JT8D-15	10.8	5.4	0.8	7.7	3.3	0.7
B733	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
B73S	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
B734	CFM56-3B	12.2	15.0	1.1	9.6	3.5	0.2
B73F	CFM56-3B	12.2	15.0	1.1	9.6	3.5	0.2
B735	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B73V	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B736	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B737	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B738	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B73A	JT8D-15	10.8	5.4	0.8	7.7	3.3	0.7
B73B	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
B73C	CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
B741	JT9D-7A	24.0	21.4	11.2	13.9	0.4	0.6
B742	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
B743	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7
B74S	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7
B744	PW4056	21.2	3.6	0.3	14.2	0.3	0.3
B74F	PW4056	21.2	3.6	0.3	14.2	0.3	0.3
B747	JT9D-7A	24.0	21.4	11.2	13.9	0.4	0.6
B74A	JT9D-7A	24.0	21.4	11.2	13.9	0.4	0.6
B74B	PW4056	21.2	3.6	0.3	14.2	0.3	0.3
B752	RB211-535E4	20.7	11.5	1.1	10.3	2.9	0.1
B753	RB211-535E4	20.7	11.5	1.1	10.3	2.9	0.1
B757	RB211-535E4	20.7	11.5	1.1	10.3	2.9	0.1
B762	CF6-80A	18.8	6.9	1.5	12.5	2.9	0.6
B763	CF6-80A	18.8	6.9	1.5	12.5	2.9	0.6
B767	CF6-80A	18.8	6.9	1.5	12.5	2.9	0.6
B777	767 * 1.34	25.2	9.3	2.0	16.8	3.9	0.8
B772	767 * 1.34	25.2	9.3	2.0	16.8	3.9	0.8
B773	767 * 1.62	30.5	11.2	2.4	20.3	4.7	1.0
BA11	RR_SPEY-512	11.4	12.7	1.6	9.3	2.6	0.5
BA46	ALF502R-5	8.8	7.9	0.8	7.7	0.2	0.0
BAC-500	RR_SPEY-512	11.4	12.7	1.6	9.3	2.6	0.5
BE1	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE10	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE18	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE19	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
BE20	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE02	BE20	8.2	4.0	0.2	8.2	4.0	0.2
C20	BE20	8.2	4.0	0.2	8.2	4.0	0.2
C12	BE20	8.2	4.0	0.2	8.2	4.0	0.2
BE23	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
BE24	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
BE30	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE3B	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE33	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE35	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE36	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE40	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BJ40	BE40	8.2	4.0	0.2	8.2	4.0	0.2
BE55	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE56	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE58	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE60	BE58	8.2	4.0	0.2	8.2	4.0	0.2
BE76	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE90	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
C21	BE90	8.2	4.0	0.2	8.2	4.0	0.2
BE95	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE99	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE9L	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BE9T	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BEK	SMTURB	8.2	3.9	0.2	8.2	3.9	0.2
BELF	C130	24.6	10.2	1.2	24.6	10.2	1.2
BL17	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
BN2P	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
BN2T	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
BN2	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
C101	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C130	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
L382	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C2	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C135	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C141	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C160	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C-160	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
ND16	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
C-17	RB211-535E4	41.5	23.0	2.2	20.6	5.8	0.2
C17	RB211-535E4	41.5	23.0	2.2	20.6	5.8	0.2
C121	F27	11.8	5.1	0.6	11.8	5.1	0.6
C150	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C152	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C172	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C72R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C177	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C77R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C182	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C82R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C185	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C206	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C207	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C208	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C212	D228	11.8	5.1	0.6	11.8	5.1	0.6
C210	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C303	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C310	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C340	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C337	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C402	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C404	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C414	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C421	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C425	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C441	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C5	JT9D-7Q	20.0	21.1	7.5	12.5	0.8	0.7
C500	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C501	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C525	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C550	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C551	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C560	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C56X	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C650	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C675	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C72R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
C750	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
CE43	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
CL2T	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
CL44	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
CL60	ALF502R-5	8.8	7.9	0.8	7.7	0.2	0.0
CL65	ALF502R-5	8.8	7.9	0.8	7.7	0.2	0.0
CARJ	ALF502R-5	8.8	7.9	0.8	7.7	0.2	0.0
CN35	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
CNJ		10.5	5.9	0.5	9.9	2.1	0.4
CONC	OLYMPUS	10.4	27.9	5.4	10.0	26.0	1.8
CONCORDE	OLYMPUS	10.4	27.9	5.4	10.0	26.0	1.8
CS12	D228	11.8	5.1	0.6	11.8	5.1	0.6
CVLT	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
CV58	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
D10-10	CF6-6D	20.6	18.3	6.8	12.6	2.2	1.4
D228	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
D328	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
D8C-33F	JT4A-11	7.3	44.9	38.4	5.4	7.4	2.0
D8S-63H	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
D9S-30	JT8D-7B	9.4	9.5	3.0	8.1	2.1	0.5
D9X-50	JT8D-17	10.7	6.1	0.8	9.4	2.3	0.5
D9Z-82	JT8D-217	14.7	5.6	1.6	10.7	3.8	1.3
DC10	CF6-6D	20.6	18.3	6.8	12.6	2.2	1.4
KC10	CF6-6D	20.6	18.3	6.8	12.6	2.2	1.4
DC3	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DC6	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DC8	JT4A-11	7.3	44.9	38.4	5.4	7.4	2.0
DC85	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
DC86	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
DC87	JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
DC9	JT8D-7B	9.4	9.5	3.0	8.1	2.1	0.5
C9	JT8D-7B	9.4	9.5	3.0	8.1	2.1	0.5
DH3	MDTURB	11.8	5.0	0.6	11.8	5.0	0.6
DH8	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DH8A	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DH8B	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DH8C	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DH5	DH6	11.8	5.1	0.6	11.8	5.1	0.6
DH6	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DHC6	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DHC7	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DHC8	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
DLR-30	CF6-50C2	21.3	18.0	6.7	12.6	2.1	1.3
DR40	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
DR44	DR40	8.1	4.0	0.2	8.1	4.0	0.2
E110	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
E120	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
E121	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
E145	CARJ	8.8	7.9	0.8	7.7	0.2	0.0
E3A	B707	8.1	32.4	26.6	6.1	4.2	1.3
E3CF	B707	8.1	32.4	26.6	6.1	4.2	1.3
E3TF	B707	8.1	32.4	26.6	6.1	4.2	1.3
EMB	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
F100	TAY620-15	11.4	15.5	2.1	8.0	3.2	1.1
FK10	TAY620-15	11.4	15.5	2.1	8.0	3.2	1.1
F10-100	TAY620-15	11.4	15.5	2.1	8.0	3.2	1.1

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
F70	FK10	11.4	15.5	2.1	8.0	3.2	1.1
FK70	FK10	11.4	15.5	2.1	8.0	3.2	1.1
F27	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
FK27	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
F28	RR_SPEY-MK555	10.5	6.0	0.5	8.5	1.5	0.4
FK28	RR_SPEY-MK555	10.5	6.0	0.5	8.5	1.5	0.4
F28-4000	RR_SPEY-MK555	10.5	6.0	0.5	8.5	1.5	0.4
F2TH	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F1	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F104	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F260	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
F4	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F14	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
VF14	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F15	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F16	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F18	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F406		10.7	5.6	0.5	8.7	1.3	0.4
RA06	F406	10.7	5.6	0.5	8.7	1.3	0.4
F5	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
F50	LGTURB	13.0	4.3	0.0	13.0	4.3	0.0
FK50	LGTURB	13.0	4.3	0.0	13.0	4.3	0.0
F60	F50	13.0	4.3	0.0	13.0	4.3	0.0
FK60	F50	13.0	4.3	0.0	13.0	4.3	0.0
F900	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
DA90	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
FA10	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
DA10	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
FA20	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
DA20	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
FA30	C421	8.1	4.0	0.2	8.1	4.0	0.2
FA50	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
DA50	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
G159	BE20	8.2	4.0	0.2	8.2	4.0	0.2
GA7	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
G2	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
GLF2	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
G3	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
GLF3	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
C20A	GLF3	10.7	5.6	0.5	8.7	1.3	0.4
G4	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
GLF4	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
G5	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
GLF5	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
G222	C130	24.6	10.2	1.2	24.6	10.2	1.2
GY80	C172	8.1	4.0	0.2	8.1	4.0	0.2
HAR	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
HAWK	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
HELI	BE20	8.2	4.0	0.2	8.2	4.0	0.2
HERN	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
HF20	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
H25A	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
H25B	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
H25C	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
HS25	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
H47	BE20	8.2	4.0	0.2	8.2	4.0	0.2
H60	BE20	8.2	4.0	0.2	8.2	4.0	0.2
IL18		49.2	23.0	2.2	49.2	23.0	2.2
I62	SOL	14.6	34.2	39.5	5.9	5.9	6.0
I72		15.1	38.7	44.5	5.8	8.0	7.9
I86	KUZ	15.1	38.8	44.7	5.8	8.1	8.0
IL62	SOL	14.6	34.2	39.5	5.9	5.9	6.0
IL72		15.1	38.7	44.5	5.8	8.0	7.9
IL76	SOL	14.6	34.2	39.5	5.9	5.9	6.0
IL86	KUZ	15.1	38.8	44.7	5.8	8.1	8.0
IL96	KUZ	15.1	38.8	44.7	5.8	8.1	8.0
J328	CARJ	8.8	7.9	0.8	7.7	0.2	0.0
JAGR	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
JS20	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
JS31	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
JS32	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
JS41	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
K135	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
K35R	CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
K35E	K35R	12.2	15.6	1.3	9.6	2.9	0.2
K35A	K35R	12.2	15.6	1.3	9.6	2.9	0.2
L101	RB211-22B	18.2	25.4	18.8	14.7	3.1	1.0
L10-1	RB211-22B	18.2	25.4	18.8	14.7	3.1	1.0
L188	MDTURB	24.6	10.2	1.2	24.6	10.2	1.2
L200	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
L29A	CL65	8.8	7.9	0.8	7.7	0.2	0.0
L29B	CL65	8.8	7.9	0.8	7.7	0.2	0.0
L39	AJET	10.7	5.6	0.5	8.7	1.3	0.4
L40	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
L410	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
OSCR	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
O410	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
L4T	SMTURB	8.2	3.8	0.2	8.2	3.8	0.2
LJ24	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR24	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ25	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR25	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ31	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR31	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
BA31	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ32	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR32	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
BA32	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ35	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR35	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ41	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR41	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
BA41	LRJ	10.7	5.6	0.5	8.7	1.3	0.4

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
LJ45	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR45	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ55	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR55	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LJ60	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LR60	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
LRJ	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MC39	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
M339	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
M6	C172	8.1	4.0	0.2	8.1	4.0	0.2
MF17	C172	8.1	4.0	0.2	8.1	4.0	0.2
MO20	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
M20P	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
M20T	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
MO2K	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
MO22	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
MD11	PW4460	19.6	7.5	0.6	13.0	1.5	0.2
MD80	JT8D-7B	9.4	9.5	3.0	8.1	2.1	0.5
MD90	JT8D-7B	9.4	9.5	3.0	8.1	2.1	0.5
MDL-11P	PW4460	19.6	7.5	0.6	13.0	1.5	0.2
MS76	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MRC	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MG29	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MIR2	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MRF1	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
MU2	SMTURB	8.4	3.7	0.2	8.4	3.7	0.2
MU20	SMTURB	8.4	3.7	0.2	8.4	3.7	0.2
MU3	SMTURB	8.4	3.7	0.2	8.4	3.7	0.2
MU30	SMTURB	8.4	3.7	0.2	8.4	3.7	0.2
N26	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
ND26	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
N262	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
NA01	SMTURB	8.4	3.6	0.2	8.4	3.6	0.2
NIM	B707	8.1	32.4	26.6	6.1	4.2	1.3
Norm	B734	12.2	15.0	1.1	9.6	3.5	0.2
P180	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P210	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P808	FA20	10.7	5.6	0.5	8.7	1.3	0.4
P27	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAZT	P27	8.1	4.0	0.2	8.1	4.0	0.2
PA24	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P28A	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P28B	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P28R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P28T	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P3	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P32R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P32T	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA38	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P66T	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
P68	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PN68	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA23	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
PA27	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA28	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PARO	PA28	8.1	4.0	0.2	8.1	4.0	0.2
PA30	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA31	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAT4	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAY1	PA31	8.1	4.0	0.2	8.1	4.0	0.2
PAY2	PA31	8.1	4.0	0.2	8.1	4.0	0.2
PA32	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA34	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PASE	PA34	8.1	4.0	0.2	8.1	4.0	0.2
PA42	PA44	8.1	4.0	0.2	8.1	4.0	0.2
PAYE	PA44	8.1	4.0	0.2	8.1	4.0	0.2
PA44	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAY3	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAY4	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA46	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA60	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PA6	SMTURB	8.4	3.6	0.2	8.4	3.6	0.2
PAY1	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAY2	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PAY3	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
PC12	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
PC6	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
PC6T	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
PC7	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
PUMA	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
R90R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
R100	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
R300	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
RALL	BE20	8.2	4.0	0.2	8.2	4.0	0.2
RANG	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
S330	BE20	8.2	4.0	0.2	8.2	4.0	0.2
AS30	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S332	BE20	8.2	4.0	0.2	8.2	4.0	0.2
AS32	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S350	BE20	8.2	4.0	0.2	8.2	4.0	0.2
AS35	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S355	BE20	8.2	4.0	0.2	8.2	4.0	0.2
AS55	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S61	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S76	BE20	8.2	4.0	0.2	8.2	4.0	0.2
S601	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
S05R	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
SB20	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
SC7	MDTURB	12.3	5.1	0.6	12.3	5.1	0.6
SM26	SB20	11.7	5.1	0.6	11.7	5.1	0.6
SBR1	MDTURB	11.8	5.1	0.6	11.8	5.1	0.6
SF3	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
SF34	MDTURB	11.7	5.1	0.6	11.7	5.1	0.6
SH33	MDTURB	12.3	5.1	0.6	12.3	5.1	0.6
SH36	MDTURB	12.3	5.1	0.6	12.3	5.1	0.6
SH5	SH6	12.3	5.1	0.6	12.3	5.1	0.6

Table B.2-1. AEM Indices for Above 3,000 Ft. Derived From BM2, Cont'd

AIRCRAFT	ENGINE	NOXTO9000	COTO9000	HCTO9000	NOXUP9000	COUP9000	HCUP9000
SH6	MDTURB	12.3	5.1	0.6	12.3	5.1	0.6
STAR	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
SW2	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
SW3	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
SW4	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
T34	SOL	9.4	9.3	2.9	8.0	2.1	0.5
T134	SOL	9.4	9.3	2.9	8.0	2.1	0.5
TU34	SOL	9.4	9.3	2.9	8.0	2.1	0.5
T154	B727	10.8	7.4	2.2	7.7	0.2	0.0
T54	B727	10.8	7.4	2.2	7.7	0.2	0.0
TU54	B727	10.8	7.4	2.2	7.7	0.2	0.0
T204	B757	20.7	11.5	1.1	10.3	2.9	0.1
TAMP	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TBM7	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TB20	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TB30	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TOBA	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TOR	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
TRIN	BE20	8.2	4.0	0.2	8.2	4.0	0.2
TRIS	BN2	8.2	4.0	0.2	8.2	4.0	0.2
TUCA	SMTURB	8.2	4.0	0.2	8.2	4.0	0.2
YK40	FA50	10.7	5.6	0.5	8.7	1.3	0.4
YK42	FA50	10.7	5.6	0.5	8.7	1.3	0.4
U2	LRJ	10.7	5.6	0.5	8.7	1.3	0.4
UH1	BE20	8.2	4.0	0.2	8.2	4.0	0.2
VC10	B707	8.1	32.4	26.6	6.1	4.2	1.3
WA42	C172	8.1	4.0	0.2	8.1	4.0	0.2
WW24	FA20	10.7	5.6	0.5	8.7	1.3	0.4
Z42	SMTURB	8.1	4.0	0.2	8.1	4.0	0.2
ZZZZ	B734	12.2	15.0	1.1	9.6	3.5	0.2

APPENDIX C
EUROPEAN SIMULATION
FLEET CHANGE AND TECHNOLOGY IMPROVEMENT METHOD

OVERVIEW

In support of the work for CAEP-WG4, "Development of a Preliminary Common Methodology to Quantify Environmental Benefits arising from CNS/ATM systems," EUROCONTROL needed to develop a methodology to estimate air traffic fuel burn and emissions. The study focuses on the years 1999, 2005, 2010, and 2015, where 1999 historical CFMU traffic data is used as baseline.

Within the methodology, it is necessary to forecast future European traffic, based on EUROCONTROL STATFOR traffic increase analysis. This leads to increased traffic samples (higher number of flights) for the years 2005, 2010, and 2015. For past studies within EUROCONTROL, increasing the number of movements for future years, based on cloning of existing movements in the base year, has been sufficient. However, for environmental studies, this simple traffic increase is not enough. One additional aspect to consider in these future traffic samples is the appearance of new, more efficient aircraft types, due to both fleet modernisation (replacement of older aircraft) and fleet expansion. So the first part of this method determines the proportion of the future fleet that will be "new" compared with the existing (baseline) aircraft. We call this the "Fleet Change Method." Once this proportion has been determined, the technological improvements and subsequent increased fuel and emission efficiency are estimated. This is referred to as the "Technology Improvement Method."

A further aspect not covered by the current EUROCONTROL method, due to its complexity, would be to consider which aircraft types will be operated on which city pair, depending on future operator strategy (more frequent flights with smaller aircraft, or less flights with larger aircraft).

C.1 FLEET CHANGE METHOD

C.1.1 INTRODUCTION

Airlines change their fleet due to the market requirements, competitiveness in the market by maintaining a youthful and up-to-date fleet, new technologies and more stringent regulations, or simply because existing aircraft have reached an age at which they are no longer economic to operate.

Modeling of emissions for future years needs to be as close as possible to the real situation. Therefore, new aircraft types and their appearance in future traffic samples have to be considered in the modeling process. Within EUROCONTROL, future traffic growth is predicted using STATFOR data, in this case, growing from the baseline year 1999.

For this particular study, representative days were selected for this baseline year, and the aircraft types found in these traffic samples were used as the basis of future fleet mixes.

Although the number of flights for future years (2005-2010-2015) is predicted, new aircraft types are not considered in the model, since the future traffic data is a cloning of the existing baseline traffic. Due to the fact that aircraft are replaced after 20-30 years, older aircraft types have to be changed in future traffic samples. For this reason, the new fleet of the future traffic data (2005-2010-2015) has to be defined.

Fleet Change methodology is used in the study to find future fleet replacement. This approach uses the concept of changing the old fleet from the baseline.

C.1.2 APPROACH / PROCESS

The process started with a review of the available data.

STATFOR traffic growth predictions are the base for future aircraft use (based on today's technology). Forecasts were produced using a Forecasting Scenario Analysis model developed by STRATAGEM, Amsterdam (RAND/EUROPE, Leiden, NL) in collaboration with EUROCONTROL. In a second step, replacement rates percentage of old aircraft in our future sample had to be found and different data sets prepared.

C.1.3 DATA USED

A number of data sources were used in order to compile a list, as complete as possible, of likely aircraft replacement rates. The following datasets should be considered to be in a descending order of data "quality". Details of these datasets are given in Appendix A.

C.1.3.1 DATASET 1

This dataset comes from the FAA (FAA/ATA/Boeing Fleet mix projections) table and represents a "yearly fleet change rank" table for different seat category and corresponding aircraft types. This dataset was used in the 1998 FAA study, "The Impact of NAS Modernization on Aircraft Emissions". European aircraft types are extracted from this table and the same yearly change rank is applied in operational days data for the baseline year 1999 to 2005, 2010, and 2015. For our traffic data, same replacement rate as in the FAA table is considered for 2005, 2010, and 2015.

C.1.3.2 DATASET 2

For this dataset, data from "JP airline fleet international" are used. An inventory is made for European airlines based on "JP airline-fleets 1998" book. For each airline, the information below collected:

Aircraft type and number

Manufacture year of the aircraft

Delivery date of the aircraft to the airline

With this data available by choosing an aircraft replacement age, replacement rates of European Airlines fleet are found for 2005, 2010, and 2015.

Assumption:

Airbus Global Market Forecast (Airbus GMF) 1999 reports an average replacement of aircraft after 24 years of operation. As a result, this means for the 2005 traffic sample, that aircraft manufactured in 1981 (2005 - 24 = 1981) have to be replaced by a new aircraft type available in 2005. Therefore, all aircraft of 1981's manufacture year have to be changed in 2005. A similar approach for other future years made:

For	2010	1986
	2015	1991

Finally, a replacement rate table was created for aircraft types. This table is based on the known aged distribution for specific aircraft types that exist in National European airlines.

C.1.3.3 DATASET 3

Similarly, from the "JP airline-fleets 1999" CD, 77 European airlines with 23 subsidiaries are investigated. The same approach as in dataset 2 is considered for the dataset 3 as a complementary, to estimate aircraft type specific replacement rates.

For those airlines, the manufacture years of the specific aircraft are found and the average manufacture year is calculated for this specific aircraft type. Then the 24 years aircraft replacement rate is used to find the future replacement from the fleet.

C.1.3.4 DATASET 4

This dataset is provided from the "1999 Airbus Global Market Forecast " [19]. The same approach in dataset 1 to produce a replacement rate for specific aircraft type appearing in the 1999 operational days. In the report, the replacement rate of the aircraft for 2018 is applied as a basis of 2015 (see Figure C.1.3.4-1).

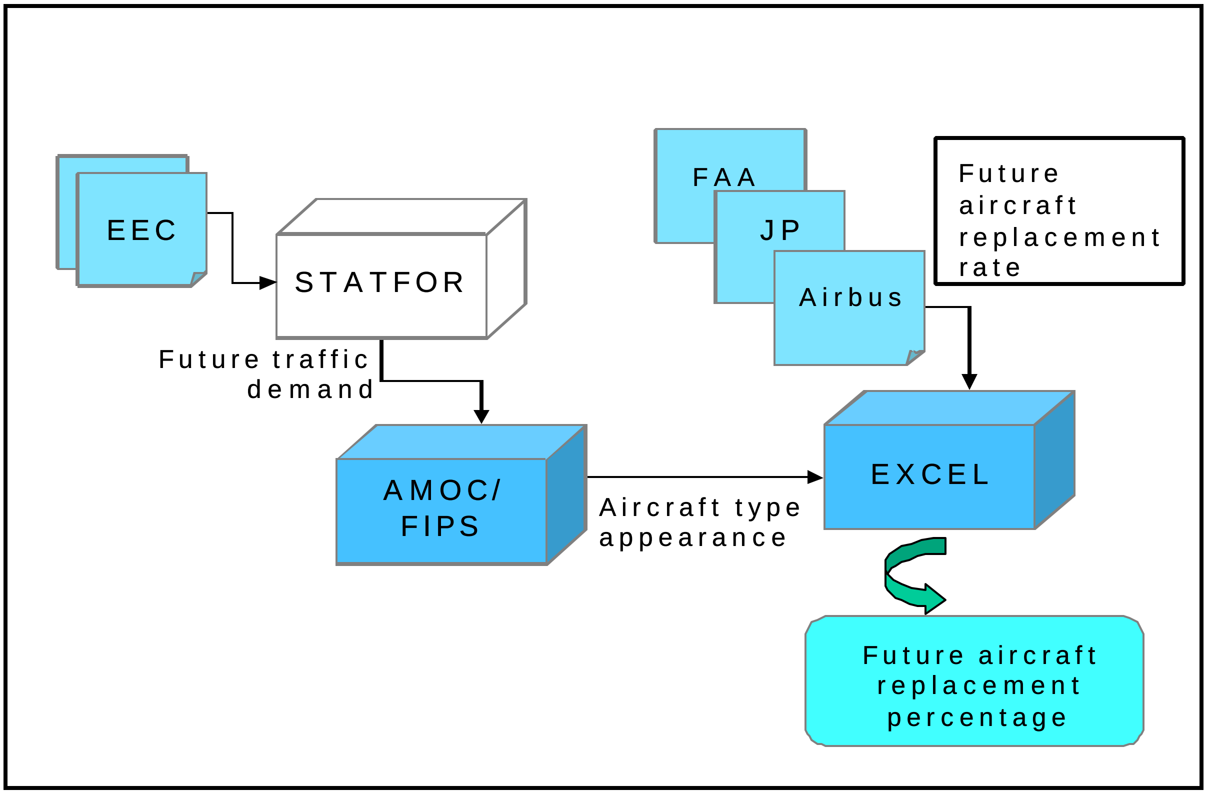


Figure C.1.3.4-1. Fleet Change Process Steps

CFMU 1999 traffic data, computed with the AMOC simulation tool to produce 4-D flight profile, delivers the list of aircraft types appearing in the 1999 traffic samples.

The 1999 traffic samples are increased based on the STATFOR forecast for the years 2005, 2010, and 2015. In the future traffic samples, aircraft types older than 24 years are replaced by future replacement types. Fir example, a B734 would be replaced in the 2005 traffic sample by a B734-2005. The percentage of replacement follows the rates estimated by the method explained earlier, using FAA, JP, and Airbus information summarized in Appendix 1.

C.1.4 COVERAGE OF THE APPROACH

Dataset 1 represents 61% of movements for that operational day; dataset 2 brings the coverage to 87% of all movements. With the complementary datasets 3 and 4, the percentage of aircraft represented is increased to 90.5%.

Note 1: The same aircraft types that exist in one dataset are not considered for the others. Note 2: Currently, this method ignores the remaining 9.5% aircraft movements for the purposes of reflecting fleet renewal/modernisation.

C.2 TECHNOLOGY IMPROVEMENT METHOD

Results of fuel burn and emission modeling for future scenarios are very dependent on the input data. From the fleet change method the percentage of aircraft types, which will change in future, are found. We do not have the information on which new aircraft type will replace the old models.

For that reason, a global engine technology improvement estimation approach is applied. This estimation is based on the information extracted from studies that indicate the fuel efficiency improvement trend on a yearly basis.

C.2.1 BASIS

Overall European traffic grows rapidly each year; therefore fuel use and emissions from the aviation are increasing as well. However fuel consumption would not increase as much as traffic growth, due to technological improvement in aircraft technology. Therefore, for the future traffic data, there is a need to find technological improvements of the aircraft to make a real assessment of fuel consumption.

C.2.2 BACKGROUND

No concrete data is available for aircraft/engine type combination and their efficiency in the future. However, studies show that there is an improvement fuel efficiency trend on a yearly basis. (IPCC Report, Rolls Royce, British Airways, NASA etc.)

C.2.3 FUEL EFFICIENCY APPROACH

Based on different fuel efficiency curves found in the literature, efficiency curves (aircraft type - year/fuel efficiency) are used to find an equation to present this trend. Data is based on the extraction of Rolls-Royce PLC information [20]. Based on historical values of yearly technological improvement, the best-fit curve is calculated by an exponential equation, which is:

$$\text{Fuel Efficiency (\%)} = (3E+24)*EXP(-0.0266*Year)$$

From this equation, fuel efficiencies are calculated for future years: 2005, 2010, and 2015 by considering the replacement age of 24 years for an aircraft. Thus, for future years, the fuel efficiency improvement is calculated by difference of 1981 data. Therefore, in our future traffic, the percentage of fuel efficiency is based on the values found from the trend line. Considering continuous improvement, efficiencies are found for 2005, 2010, and 2015 (see Table C.2.3-1).

Table C.2.3-1. Fuel Efficiency Factors for Future

Future Year	Fuel Efficiency
2005	18.5 %
2010	21.0 %
2015	23.2 %

Those values are applied to the future replacement aircraft types. Coming back to the example used earlier in this document, we explained that in the 2005 traffic sample a certain percentage of B734s would be replaced by B734-2005. Lastly, "future" aircraft type fuel burn data was inherited from the B734, but an 18.5% fuel burn efficiency improvement was applied to represent the expected technology improvement.

The combination of aircraft type replacement rate and increase fuel efficiency leads to the modifications of the 1999 traffic sample in the way documented below.

2005	18.5% Fuel efficiency increase applied to replacement percentage for 2005 aircraft types
2010	See above comment [(18.5)*(Replacement percentage for 2005)]+[(21) * (Replacement percentage for 2010 - Replacement percentage for 2005)
2015	See comment for 2005{[(18.5)*(Replacement percentage for 2005)]+[(21) * (Replacement percentage for 2010 - Replacement percentage for 2005)] + [(23.2) * (Replacement percentage for 2015 - Replacement percentage for 2010)]}

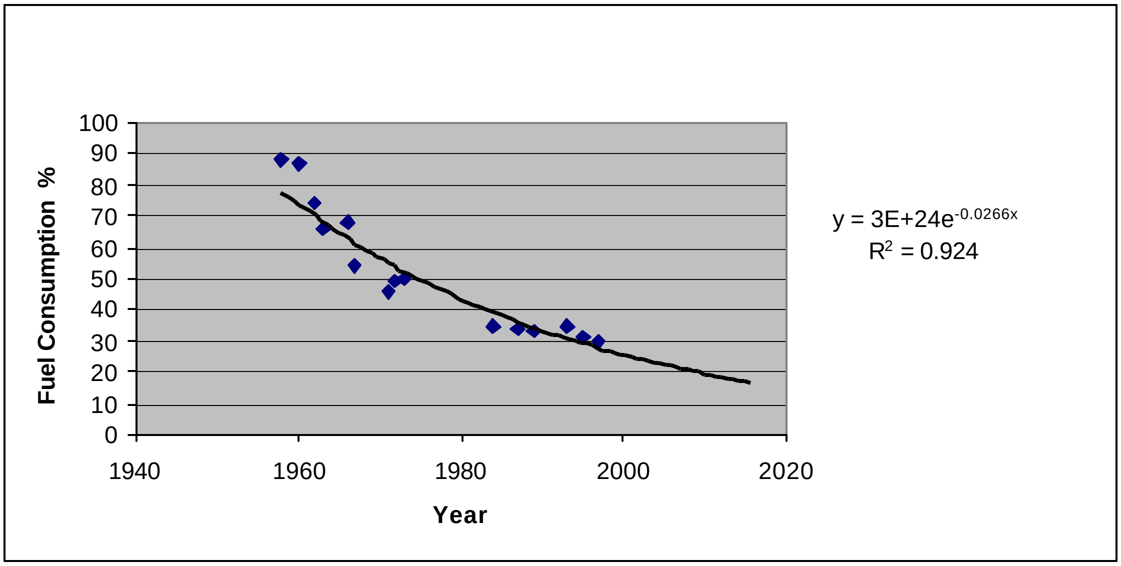


Figure C.2.3-1. Fuel Efficiency Improvement Curve

For example in the year 2015, the combination of aircraft type replacement and fuel burn efficiency improvement will lead to the following:

In 2005, 4.893% B733s will be replaced by B733 aircraft with 18.5% improved fuel efficiency.

In 2010, 28.746% B733s will be replaced by B733 aircraft with 21% improved fuel efficiency.

In 2015, 18.196% B733s will be replaced by B733 aircraft with 23.2% improved fuel efficiency.

The fuel efficiency improvement was compared to the B733 fuel burn information. For each phase (LTO/cruise/descent/taxi) in the fuel burn calculation, values are reduced with the efficiency values calculated.

C.2.4 VERIFICATION OF THE METHOD

For the sensitivity analysis of the approach, different studies are used to compare the fuel efficiency values (see IATA Annual Report [20]). Based on Figure C.2.3-1, which depicts the fuel efficiency trend line from 1955 to 2015, and by considering the 24 years replacement age, comparison is made for 2005, 2010, and 2015 efficiency values found in a National Research Council Report [21].

The same approach is used for 2005. For 2005, 2010, and 2015, efficiencies are 19% (18.5) - 21% (21), and 22% (23.2), respectively, which compares very well.

C.3 CONCLUSION

The approach explained in this document is based on the application of the general engine technology improvement trend. It applies this information to generic future replacement aircraft types, where it considers that aircraft types will be replaced by similar aircraft types in the future after a given period of operation (see Table C.3-1). For a more accurate modeling of future air traffic, more detailed information about airlines intentions to replace today's aircraft by different category aircraft would be desirable.

Table C.3-1. Aircraft Replacement Rate

DATASET 1				
Class	Type	2005	2010	2015
2	B721			
2	B722			
2	Total B727	54.819%	100.000%	100.000%
2	B732	57.035%	97.739%	100.000%
2	B733	4.893%	33.639%	51.835%
2	B734	0.000%	13.043%	53.913%
2	B735	0.000%	11.864%	60.452%
2	A320	0.000%	15.842%	66.997%
2	BA11	100.000%	100.000%	100.000%
2	BA46	5.109%	33.577%	71.533%
2	DC87	100.000%	100.000%	100.000%
2	DC9-10	100.000%	100.000%	100.000%
2	DC9-30	39.286%	100.000%	100.000%
2	DC9-40	100.000%	100.000%	100.000%
2	DC9-50	100.000%	100.000%	100.000%
	total DC9	51.977%	100.000%	100.000%
2	F-100	0.000%	13.669%	49.640%
2	F-28	100.000%	100.000%	100.000%
2	MD-81	9.459%	74.324%	98.649%
2	MD-82	5.396%	44.604%	82.374%
2	MD-83	2.752%	27.523%	76.147%
2	MD-87	0.000%	54.545%	98.182%
2	MD-88	0.000%	0.741%	25.926%
DATASET 1				
	total MD80	4.306%	39.182%	75.673%
2	T154	65.517%	93.103%	100.000%
3	B757	3.003%	18.619%	43.544%
3	A310	26.437%	71.839%	94.828%
4	B74S	83.333%	100.000%	100.000%
4	L101	54.167%	100.000%	100.000%
4	DC10	75.000%	96.875%	100.000%
4	B767	21.749%	72.340%	94.563%
4	A30B	78.704%	100.000%	100.000%
4	A306	0.000%	32.258%	80.645%
5	DC10	79.310%	98.276%	100.000%
5	IL86	100.000%	100.000%	100.000%
5	MD11	3.509%	17.544%	82.456%
5	B743	40.625%	96.875%	100.000%
5	B744	4.294%	37.423%	93.865%
5	B741	100.000%	100.000%	100.000%
5	B742	89.091%	99.091%	100.000%
	B74R	54.545%	63.636%	95.455%

Table C.3-1. A/C Replacement Rate, Cont'd

DATASET 2

Class	Type	2005	2010	2015
	AN12	100%	100%	100%
	AN24	100%	100%	100%
	AT43			50%
	AT72			17%
	ATP			80%
	B707	100%	100%	100%
	C310	100%	100%	100%
	C550			100%
	CONC*	100%	100%	100%
	DHC6	100%	100%	100%
	F27	100%	100%	100%
	F50			36%
	F900			100%
	IL18	100%	100%	100%
	IL62	100%	100%	100%
	PA34		100%	100%
	PAY3			100%
	SF34		100%	100%
	T134	100%	100%	100%
	YK40	100%	100%	100%
	YK42			50%

DATASET 3

Class	Type	2005	2010	2015
	A748	100%	100%	100%
	B190			100%
	BE10	100%	100%	100%
	BE20		100%	
	BE58	100%	100%	100%
	BE95	100%	100%	100%
	BE9L	100%	100%	100%
	BE9T		100%	100%
	D228			100%
	DH8A			100%
	DH8C			100%
	E120			100%
	FA20	100%	100%	100%
	FA50		100%	100%
	JS31		100%	100%
	LJ35	100%	100%	100%
	SH36			100%
	SW3	100%	100%	100%
	SW4	100%	100%	100%
	TRIN			100%

DATASET 4

Class	Type	2005	2010	2015
	A319			35%
	A321			100%
	A330			70%
	A340			76%
	B737			19%
	B738			22%
	B772			55%
	F70			78%

* Replacement age of Concorde is generally higher than other aircraft

APPENDIX D
EMISSION INDEX FOR CO_2, H_2O, AND SO_2

D.1 INTRODUCTION

Future subsonic aviation emissions of CO_2 are expected to be much higher than previously anticipated. At present, aviation contributes about 3% of CO_2 from all global fossil fuel burning, and over 2% of CO_2 from all sources. The principal emissions of global concern are: carbon dioxide (CO_2), water vapour (H_2O), oxides of nitrogen (NO_x) and particulates (soot and sulphur compounds).

In the study, for different operational mode and flight altitudes, emission indices are used for oxides of nitrogen (NO_x), carbon monoxide (CO), and hydrocarbons (HC). As H_2O, CO_2, and SO_2 are the emissions directly produced from oxidation of fuel, their emission indices in any flight mode are a constant index (multiplied by the fuel used).

CO_2 and H_2O are the products of direct oxidation of fuel carbon and hydrogen through interaction with atmosphere oxygen. SO_2 derives from oxidation of the trace sulphur found in jet fuel. The sulphur contents for commercial jet fuel are generally around 0.3% of weight.

Operational procedures do not affect these species but the composition of the fuel type is important. Therefore, a literature study is done for fuel composition and emission index.

D.2 FUEL TYPES USED IN AVIATION

EIA energy statistics distinguish between two classes of jet fuel: "naphtha-based" and "kerosene-based." Naphtha-based jet fuels, used almost entirely by the military, account for less than 10 percent of total consumption. Kerosene-based jet fuel is believed to consist predominantly of civil-grade Jet A (used by commercial airliners) and its military version, JP5. Other kerosene-based jet fuels include the military JP7 and JP8. Naphtha-based jet fuel products include civil Jet B and the military grades JP1, JP3, and JP4. There is considerable variation in density and carbon content across the various types of jet fuel, but actual consumption is believed to consist largely of Jet A and JP5.

In estimating emissions coefficients for petroleum products, it is useful to determine three attributes for each product:

The density, or how many kilograms a barrel of the product weighs

The portion of the weight of the product that is hydrocarbons, and the portion that is non-hydrocarbon impurities

The families of hydrocarbons that make up the hydrocarbon portion

Since there are different types of fuel used in the aviation sector and there is no specific data about the composition of fuel, it is difficult to estimate the exact constant value. Therefore, average values of emission constants of the different studies are used. An average value is chosen for each emission and used in AEM calculation step.

Aviation fuel varies depending on the oil source and refining process: the bulk physical and chemical properties are controlled by specification, e.g. DERD 4294, ASTM D 1655 for aviation jet fuel. Within this specification, the hydrogen content of the fuel must be between 13.4 and 14.1 % by mass, and the total sulphur content must be no more than 0.3 % by mass. A number of large-scale surveys of actual fuel quality have been carried out (see Table D.2-1).

Table D.2-1. Hydrogen and Sulphur Content of Aviation Fuel

Source	Hydrogen% by Mass (Mean)	Sulphur % by Mass (Mean)	Sulphur Fraction <0.1 % by Mass	Comments
Hadaller & Momethy	13.8	0.042	0.9	Samples taken from airports around the world
Rickard	13.83	0.045	0.86	Samples from aviation fuel supplied in UK.
ICAO fuel specification	13.4-14.1	< 0.3	-	

Typical sulphur levels in aviation kerosene are in the range 0.04-0.05 % by weight, with a slight downward trend over the last decade compared with the allowed specification limit 0.3% (ICAO; 1981; 1993). Fuel samples taken from various European test facilities and from a range of airports worldwide were analysed as part of the European AEROTRACE programme [22] and support other surveys. Sulphur levels were in the range 0.003-0.06% and hydrogen content 13.54-13.96 %. With the assumption of complete combustion, the emission indices for CO_2, H_2O, and SO_2 depend on m_C, m_H, and m_S, the carbon, hydrogen, and sulphur mass contents of the fuel; typically m_H = 0.138?0.02, m_S =450ppm(1ppm=10-6) and $m_C = 1-m_H-m_S$.

$$EI_{CO2} = m_C M_{CO2} / M_c - 3.15 \quad \text{Eq.1}$$
$$EI_{H2O} = m_H M_{H2O} / M_{H2} \ ?\ 1.24 \quad \text{Eq.2}$$
$$EI_{SO2} = m_S M_{SO2} / M_S \ ?\ 0.8 \text{ g/kg} \quad \text{Eq.3}$$

D.3 EMISSION INDICES FOR CO_2, H_2O, SO_X FROM DIFFERENT STUDIES

Emission indices for CO_2, H_2O, and SO_x are summarized in Table D.3.1 below.

Table D.3-1. Emission Indices From Different Sources (g/kg fuel)

Reference	CO_2	H_2O	SO_2
Meet Report			
ECAC	3100	1240	
TUV			0.9789
Olivier	3220	1250	1
Switzerland			0.9844
Netherlands	3168	1242	0.207
Guidebook	3133	1266	1
Norway			0.32
Atmospheric Environment Vol.32 No 13 pp. 2329-2418;1998			
G.P. Brasseur	3160	1230	1
Short haul/B757/555km	Taxi-Toff-Climb-out: 3130 Climb-Cruise-Descent: 3150 App-land-taxi: 3140	Taxi-Toff-Climb-out: 1220 Climb-Cruise-Descent: 1229 App-land-taxi: 1233	Taxi-Toff-Climb-out: 1 Climb-Cruise-Descent: 1 App-land-taxi: 0.93
Long Haul /DC10-30/8750 km	Taxi-Toff-Climb-out: 3143 Climb-Cruise-Descent: 3150 App-land-taxi: 3136	Taxi-Toff-Climb-out: 1226 Climb-Cruise-Descent: 1230 App-land-taxi: 1227	Taxi-Toff-Climb-out: 1.01 Climb-Cruise-Descent: 0.99 App-land-taxi: 1.06
BEAM			
	3154	1170	0.6(for 0.3 %)
DLR			
			0.2-0.8
NASA			
	3155	1237	0.8
IPCC 1999			
	3150 ? 10	1250 ? 30	0.8 - 1.2

D.4 EMISSION INDEX FOR CO_2, H_2O, AND SO_X

The emission indices for CO_2, H_2O, and SO_x are constant, however the exact values are dependent on the chemical composition of the fuel considered (Eq.1-2-3). There are different types of fuel used in the aviation sector, therefore it is difficult to estimate the exact value, and instead the average values of the different studies can be used. As shown in Table D.3-1), during different phases, the values from the G.P. Brasseur study can be used in different phases of flight. Table D.3-1 also shows the average values as:

CO_2	H_2O	SO_2
3149	1230	0.84

or the short haul considered for Europe:

CO_2
Taxi-Toff-Climb-out: 3130
Climb-Cruise-Descent: 3150
App-land-taxi: 3140

H_2O
Taxi-Toff-Climb-out: 1220
Climb-Cruise-Descent: 1229
App-land-taxi: 1233

SO_2
Taxi-Toff-Climb-out: 1
Climb-Cruise-Descent: 1
App-land-taxi: 0.93

D.5 ALTERNATIVE APPROACH FOR SO_2 INDEX

For the future SO_2 indices, the efficiency factor can be estimated as:
From IPCC 99 report, present average sulphur content is around 0.04-0.06 % (resulting EI SO_2 of 0.8-1.2).

There is a direct correlation between the sulphur content and emission indices. From the sulphur trend curve of IPCC report (pp. 256); the efficiency is 6.5% per ten years (1986 to 1996); if we use the same range for future sulphur content the emission indices are found:

1999 ? 0.86 (baseline)
2005 ? 0.78
2010 ? 0.73
2015 ? 0.68

APPENDIX E
EUROPEAN SIMULATION RESULTS

		03.07.1999	07.07.1999	23.07.1999	3day Avg. 99*	Avg. 99**
		1999				
Flight		20,522	24,203	25,139	23,288	22,175
Tot. Flighttime	hours	34,550	35,899	37,812	36,087	34,526
Avg.Flighttime		1.684	1.483	1.504	1.557	
Tot. Fuelburn	tons	106,420	98,516	104,754	103,230	99,219
Avg. Fuelburn		5.186	4.07	4.167	4.474	
Tot. CO2	tons	335,115	310,228	328,869	324,738	312,145
Avg. CO2		16.33	12.818	13.082	14.076	
		2005				
Flight		27,124	31,855	33,242	30,740	29,271
Tot. Flighttime	hours	46,160	47,679	50,597	48,146	46,060
Avg.Flighttime		1.702	1.497	1.522	1.574	
Tot. Fuelburn	tons	135,166	124,603	133,552	131,107	125,987
Avg. Fuelburn		4.983	3.912	4.018	4.304	
Tot. CO2	tons	425,639	392,376	420,556	412,857	396,734
Avg. CO2		15.692	12.318	12.651	13.554	
		2010				
Flight		32,483	38,175	39,874	36,844	35,083
Tot. Flighttime	hours	55,551	57,390	60,949	57,963	55,455
Avg.Flighttime		1.71	1.503	1.529	1.581	
Tot. Fuelburn	tons	154,586	142,676	153,421	150,228	144,356
Avg. Fuelburn		4.759	3.737	3.848	4.115	
Tot. CO2	tons	486,791	449,288	483,124	473,068	454,577
Avg. CO2		14.986	11.769	12.116	12.957	
		2015				
Flight		37,666	44,275	46,312	42,751	40,708
Tot. Flighttime	hours	64,465	66,533	70,881	67,293	64,382
Avg.Flighttime		1.711	1.503	1.531	1.582	
Tot. Fuelburn	tons	166,773	154,084	165,328	162,062	155,744
Avg. Fuelburn		4.428	3.48	3.57	3.826	
Tot. CO2	tons	525,167	485,211	520,619	510,332	490,438
Avg. CO2		13.943	10.959	11.242	12.048	

*The average of three representative days

**The average of yearly distribution

APPENDIX F
SIMULATION MODEL VERIFICATION

Table F-1. Verification with Real Airline Values

CALL SIGN	DEP_AIRPORT	ARR_AIRPORT	A/C TYPE	AEM	Real Airline Data	Correlation
DLH4428	EDDF	EBBR	A320	1944.37	2014	96.5%
SAB418	EDDF	EBBR	B734	2254.97	2243	100.5%
DLH010	EDDF	EDDH	A310	3054.34	4590	66.5%
DLH118	EDDF	EDDM	A321	2488.02	2202	113.0%
DLH372	EDDF	EDDN	A320	1486.84	1573	94.5%
DLH062	EDDF	EDDP	A320	2033.61	2109	96.4%
DLH004	EDDF	EDDH	A320	2236.78	2742	81.6%
DLH048	EDDF	EDDH	A321	2236.78	2907	76.9%
DLH290	EDDF	EDDK	B733	969.88	1301	74.5%
DLH292	EDDF	EDDK	A319	1000.01	1106	90.4%
DLH294	EDDF	EDDK	A320	1000.01	1114	89.8%
DLH296	EDDF	EDDK	A320	1000.01	1102	90.7%
DLH208	EDDF	EDDL	A320	1621.56	1681	96.5%
DLH210	EDDF	EDDL	A321	1621.56	1822	89.0%
DLH212	EDDF	EDDL	A321	1621.56	1794	90.4%
DLH214	EDDF	EDDL	B733	1612.14	1761	91.5%
DLH118	EDDF	EDDM	A321	2488.02	2175	114.4%
DLH126	EDDF	EDDM	A306	2764.11	3621	76.3%
DLH142	EDDF	EDDM	A320	2488.02	1910	130.3%
DLH144	EDDF	EDDM	A320	2488.02	1954	127.3%
DLH158	EDDF	EDDM	A310	2467.80	3178	77.7%
DLH372	EDDF	EDDN	A320	1486.84	1538	96.7%
DLH062	EDDF	EDDP	A320	2033.61	1573	129.3%
DLH044	EDDF	EDDS	A320	1518.95	1215	125.0%
DLH046	EDDF	EDDS	B733	1507.19	1280	117.7%
DLH398	EDDF	EDDS	A320	1452.95	1248	116.4%
DLH2400	EDDF	EDDT	A321	2633.22	3248	81.1%
DLH2406	EDDF	EDDT	A320	2633.22	2974	88.5%
DLH014	EDDF	EDDV	A320	2236.43	2009	111.3%
DLH4953	EDDF	EDDV	A321	2236.43	2149	104.1%
DLH196	EDDF	EDDW	A320	2350.11	2354	99.8%
DLH4810	EDDF	EDDW	A321	2386.51	2528	94.4%

APPENDIX G
THEORETICAL FOUNDATION OF THE PARAMETRIC MODEL

G.1 INTRODUCTION

This section describes how the various parameters are estimated. First, an overview is given and then some of the components are discussed in detail.

The basic model uses a series of assumptions and input data to estimate aircraft fuel usage and emissions in the global environment. The primary components are U.S. and European flights with the remainder of the globe estimated based on flights from the OAG and forecasts from FESG.

In order to develop a parametric model, variables that can influence fuel consumption were identified. Fuel consumption varies drastically by phase of flight, so each phase was studied separately. These phases of flight are surface, take-off, initial climb, cruise and approach. Another obvious variable is aircraft by type and engine. Forecasting how the aircraft types will evolve in the future and the ability to adjust the future fuel burn estimates accordingly was necessary. This is discussed in section G.8.

Demand growth and airport capacities can affect ground and arrival delays. Some CNS/ATM initiatives will increase airport capacities, reducing delays. For the U.S., we have taken delays at arrival airport, as well as taxi-out delays from the simulation results. For Europe, delays at arrival airports are estimated using arrival delays, i.e. difference between actual arrival and scheduled arrival, using AEA [15] report. This is described further in section G.12.2. Taxi-out delays are estimated using airline surveys conducted by EUROCONTROL and European simulation inputs.

It can be shown that delays and capacities are related inversely in a nonlinear fashion. We used queueing theory approximations to estimate percent delay reduction due to capacity increases resulting from some CNS/ATM initiatives. See section G.9 for more detail.

Airport capacity varies under different weather conditions. We have airport capacities for 80 major airports in the U.S. for both VFR and IFR weather conditions. For Europe, we have airport capacities for over 90 airports for VFR conditions, around 20 of which are capacity constrained airports. See Table G.9.2-1 for a list. We assumed that IFR capacities in Europe are 68% of VFR capacities; 68% is the median ratio of IFR to VFR capacity in U.S. In order to calculate the average capacities at these airports, we needed the likelihood (probability) of VFR or IFR weather conditions at each airport. This probability was based on 40 years of National Climatic Data Center (NCDC) surface weather data [4] climatological observation spanning for the U.S. and Europe. Currently, we have NCDC weather data for the entire globe for specific stations. When we could not find an airport in the NCDC database, the closest airport geographically was used. The list of substituted airports in Europe is provided in Table G.10-1.

As mentioned earlier, demand and airport capacities affect ground and delays at arrival airport. One of the features added to this parametric model is to approximate percent fuel consumption decreases (increases) due to adding (delaying) CNS/ATM initiatives.

G.2 DATA PREPARATION

The simulation done for the FAA study [1] was the starting point for the parametric model. We had over 48,000 flights for the base year 1996 and for 2005, 2010, and 2015. Each flight simulation produced outputs containing time and fuel consumption for take-off, climb, cruise, and approach. The time and fuel consumption for the approach phase contained delays at the arrival airport. We first subtracted the delays at the arrival airport from the approach phase of flight to get "unimpeded" approach time.

As expected, the simulation results show that take-off, climb and approach (without delays) are aircraft dependent and not airport dependent. We assumed the CNS/ATM measures may reduce cruise time and delays but not fuel consumption rates (fuel usage per minute of operations) or take-off, climb and unimpeded approach times. We further assumed that engine design and fleet changes could contribute to such improvements. Thus, for fuel burn rate and time, we use the entire data set (baseline and optimal scenarios), and calculated the 50th (median), 16th (low), and 84th (high) percentiles, as well as the average fuel burn and for climb, take-off, and unimpeded approach.

The simulation contained some outliers that probably resulted from bad input data. Bad input data may result from radar data error bounds captured in the Enhanced Traffic Management System (ETMS), the fact that updates on aircraft position are recorded every two to three minutes, data corruption during file transfer, and so on. Thus, we used the median as opposed to average for all relevant parameters, as the former is more resistant to outliers. Similarly, we used the low and high percentiles to calculate variable bounds instead of doing calculations with the standard deviation.

Next we obtained actual daily counts of IFR flights flown in CONUS for 1999 from ETMS database. The sample data contained unknown aircraft type, i.e. aircraft types not found in the original FAA Study [1]. These were mapped to known aircraft types used in that study (see Table G.2-1)

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Table G.2-1. Mapped Unknown Aircraft Type to Known Aircraft

Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown aircraft	Mapped to
0815	BE58	**AA5**	AA5	**AT45**	AT42	**B741**	B74F	**BE40**	BE40	**C17R**	C172	**C650**	C650	**DA21**	DA20
0W3	BE58	**AA5A**	AA5	**AT72**	AT42	**B742**	B74F	**BE50**	BE55	**C180**	C182	**C69**	C23	**DA22**	DA20
1F16	F16	**AA5B**	AA5	**ATLA**	AT42	**B743**	B74F	**BE55**	BE55	**C182**	C182	**C72R**	C172	**DA50**	DA20
25C	BE58	**AA7**	AA5	**ATP**	BA46	**B744**	B74F	**BE58**	BE58	**C185**	C182	**C72T**	C172	**DA90**	DA20
2CL4	BE58	**AC11**	AA5	**ATR**	BA46	**B747**	B747-200	**BE60**	BE60	**C18R**	C182	**C750**	BE58	**DC10**	DC10-30
2F18	F18	**AC12**	AA5	**AV8**	AJ25	**B747-200**	B747-200	**BE65**	BE60	**C2**	C12	**C77R**	BE58	**DC10-30**	DC10-30
2T38	BE58	**AC14**	AA5	**AV8B**	AJ25	**B74A**	B747-200	**BE76**	BE76	**C20**	C206	**C82R**	BE58	**DC3**	DC3
328	BE58	**AC2A**	AA5	**B06**	BE60	**B74B**	B74F	**BE77**	BE76	**C201**	C206	**C9**	C9	**DC6**	DC6
332	A300	**AC50**	AC50	**B1**	B1	**B74F**	B74F	**BE80**	BE8T	**C205**	C206	**C90**	C9	**DC8**	DC86
34	BE58	**AC60**	AC69	**B100**	BE58	**B74R**	B74R	**BE8T**	BE8T	**C206**	C206	**CA21**	CA21	**DC85**	DC86
35	BE58	**AC68**	AC69	**B12**	BE58	**B74S**	B74R	**BE9**	BE90	**C207**	C208	**CA7**	CA21	**DC86**	DC86
38A	BE58	**AC69**	AC69	**B17**	C23	**B752**	B757-200	**BE90**	BE90	**C208**	C208	**CARJ**	CRJ	**DC87**	DC86
421	BE58	**AC6T**	AC69	**B18T**	BE58	**B753**	B757-200	**BE95**	BE90	**C21**	C21	**CE43**	C560	**DC8S**	DC86
46	BE58	**AC80**	AC69	**B19**	BE18	**B757**	B757-200	**BE99**	BE99	**C210**	C210	**CE56**	C560	**DC9**	DC9-50
5215	BE58	**AC84**	AC69	**B190**	BE30	**B757-200**	B757-200	**BE9C**	C21	**C212**	C210	**CH47**	BE58	**DC9-50**	DC9-50
6123	BE58	**AC90**	AC69	**B2**	B52	**B762**	B767-200	**BE9F**	C21	**C23**	C23	**CL21**	CL44	**DE10**	BE58
727	B727-200	**AC95**	AC69	**B20**	BE20	**B763**	B767-200	**BE9G**	C21	**C25**	C23	**CL22**	CL44	**DH2**	DH2
736	B73S	**ACT**	AC50	**B200**	BE02	**B767**	B767-200	**BE9L**	C21	**C26**	CA21	**CL2T**	CL44	**DH3**	DH3
737	B73S	**AE32**	C421	**B206**	DH8	**B767-200**	B767-200	**BE9T**	C21	**C27**	C23	**CL41**	CL44	**DH6**	DH6
737B	B73S	**AEST**	C421	**B222**	BE20	**B772**	B777	**BEL9**	DH8	**C2O8**	C208	**CL44**	CL44	**DH7**	DH8
757	B757-200	**AFTR**	BE58	**B337**	BE33	**B773**	B777	**BELF**	BE10	**C303**	CL61	**CL60**	CL60	**DH8**	DH8
767	B767-200	**AG3**	BE58	**B35**	BE35	**B777**	B777	**BEST**	BE10	**C310**	C310	**CL61**	CL61	**DH83**	DH8
773	B777	**AG5B**	BE58	**B350**	BE35	**B9L**	BE58	**BH06**	BE58	**C320**	CL61	**CL64**	CL61	**DH8A**	DH8
777	B777	**AH1**	DH8	**B36T**	BE35	**BA02**	BA31	**BH12**	BE58	**C335**	CL61	**CL65**	CL61	**DH8B**	DH8
815	BE58	**AH1W**	BE58	**B52**	B52	**BA10**	BA11	**BH22**	BE58	**C336**	CL61	**CLRJ**	CL44	**DH8C**	DH8
A1	A10	**AH64**	DH8	**B55**	BE55	**BA11**	BA11	**BH41**	BE58	**C337**	CL61	**CM11**	BE58	**DHC**	DH8
A10	A10	**AJ25**	AJ25	**B58**	BE58	**BA14**	BA14	**BH43**	BE58	**C340**	C340	**CN35**	BE58	**DHC2**	DH8
A106	A6	**AJET**	ARJ	**B701**	B707	**BA31**	BA31	**BHO6**	BE58	**C401**	C401	**CNC**	BE58	**DHC3**	DH8
A109	AJ25	**AK76**	BE58	**B703**	B707	**BA32**	BA31	**BJ40**	BE58	**C402**	C402	**CONC**	CONC	**DHC6**	DH6
A124	B747-200	**ALOR**	BE58	**B707**	B707	**BA41**	BA41	**BK17**	BE58	**C404**	C402	**Concorde**	CONC	**DHC7**	DH8
A20	A320	**AMX**	BE58	**B72**	B727-200	**BA46**	BA46	**BL17**	BE58	**C406**	C402	**CRJ**	CRJ	**DHC8**	DH8
A300	A300	**AN12**	AN12	**B720**	B727-200	**BATP**	BATP	**BL26**	BE58	**C411**	C414	**CS12**	BE58	**DO28**	BE90
A306	A300	**AN24**	AN12	**B721**	B727-200	**BE02**	BE02	**BL30**	BE58	**C414**	C414	**CS5**	C5	**DO32**	D328
A30B	A300	**AN26**	BE58	**B722**	B727-200	**BE10**	BE10	**BN2**	BN2	**C42**	C421	**CV24**	WW24	**DO38**	D328
A310	A310	**AN28**	BE58	**B727**	B727-200	**BE18**	BE18	**BN2P**	BN2	**C421**	C421	**CV34**	WW24	**DO82**	DA20
A319	A320	**AN30**	BE58	**B727-200**	B727-200	**BE19**	BE18	**BN2T**	BN2	**C425**	C425	**CV44**	WW24	**DR40**	BE58
A32	A320	**AN32**	BE58	**B73**	B73S	**BE1L**	BE18	**BS46**	BE58	**C440**	C441	**CV58**	CV58	**DSH8**	BE58
A320	A320	**AN6**	AN12	**B731**	B73S	**BE2**	BE20	**BST**	BE58	**C441**	C441	**CV60**	CL61	**E110**	E110
A321	A320	**AN72**	BE58	**B732**	B73S	**BE20**	BE20	**C12**	C12	**C5**	C5	**CV64**	CL61	**E120**	E120
A330	A300	**ARCF**	BE58	**B733**	B73S	**BE23**	BE33	**C125**	C12	**C500**	C500	**CVLP**	BE58	**E121**	E120
A340	A320	**ARJ**	ARJ	**B734**	B73S	**BE24**	BE33	**C130**	C130	**C501**	C501	**CVLT**	CV58	**E145**	N265
A340-600	A320	**AS32**	BE58	**B735**	B73S	**BE2H**	BE20	**C135**	C130	**C502**	C501	**D082**	BE58	**E2**	E2
A3ST	A300	**AS50**	BE58	**B736**	B73S	**BE3**	BE30	**C140**	C141	**C525**	C550	**D228**	D28	**E3**	C5
A4	A4	**AS55**	BE58	**B737**	B73S	**BE30**	BE30	**C141**	C141	**C55**	C560	**D28**	D28	**E3CF**	C5
A40	A4	**AS65**	BE58	**B738**	B73S	**BE31**	BE30	**C150**	C152	**C550**	C560	**D328**	D328	**E3D**	C5
A4F	A4	**ASTR**	BA46	**B73A**	B73S	**BE33**	BE33	**C152**	C152	**C551**	C560	**D329**	D328	**E3TF**	C5
A6	A6	**AT1**	AT42	**B73B**	B73S	**BE35**	BE35	**C160**	C172	**C56**	C560	**DA01**	DA01	**E6**	C5
A7	A6	**AT38**	AT42	**B73C**	B73S	**BE36**	BE36	**C17**	C172	**C560**	C560	**DA02**	DA02	**E9**	AJ25
A748	BE58	**AT42**	AT42	**B73F**	B73S	**BE3B**	BE3B	**C172**	C172	**C56X**	C560	**DA05**	DA05	**EA32**	AC69
AA1	AA5	**AT43**	AT42	**B73S**	B73S	**BE3L**	BE30	**C175**	C177	**C580**	C560	**DA10**	DA10	**EA34**	WW24
AA22	AA5	**AT44**	AT42	**B74**	B74F	**BE4**	BE40	**C177**	C177	**C60**	C650	**DA20**	DA20	**EA6**	EA6

Table G.2-1. Mapped Unknown Aircraft Type to Known One, Cont.

Unknown aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown aircraft	Mapped to	Unknown aircraft	Mapped to	Unknown Aircraft	Mapped to	Unknown Aircraft	Mapped to
EA6B	EA6	G115	BE58	HU25	BE58	LJ31	LR31	MS76	A10	PA44	PA42	SH33	AJ25	TOR	A10
EAST	BE58	G159	G159	HW50	BE58	LJ34	LR35	MT35	BE58	PA46	PA46	SH36	SH7	TRIN	BE58
EC35	BE58	G2	G2	HXA	BE58	LJ35	LR35	MU2	MU2	PA56	PA60	SH6	SH7	TRIS	PA31
EH60	BE58	G21	N265	HXB	BE58	LJ36	LR35	MU2B	MU2	PA60	PA60	SH7	SH7	TS60	AC69
ER2	AJ25	G222	PA28	HXC	BE58	LJ39	LR35	MU2P	MU2	PAAT	PA60	SHD3	SHD3	TS61	AC69
ES3	BE58	G3	G3	HXE	BE58	LJ45	LR35	MU3	MU3	PARO	PARO	SJ20	BE58	TU34	TU34
F100	FK10	G4	G4	IL18	C130	LJ5	LR55	MU30	MU30	PASE	PASE	SK76	BE58	TU5	TU5
F104	FK10	G5	CL60	IL62	B707	LJ55	LR35	MXT7	BE58	PAT4	PA42	SRB1	BE58	TUCA	TU5
F111	A4	G73	G73	IL76	IL96	LJ60	LR60	N22B	N22B	PAY1	PA42	STAR	C421	TYPE	BE58
F117	F18	GA7	BE20	IL86	IL96	LR23	LR24	N260	N265	PAY2	PA42	SW2	SW3	U2	U21
F14	F14	GC1	BE58	IL96	IL96	LR24	LR24	N262	N265	PAY3	PA42	SW2A	SW3	U21	U21
F15	F15	GL20	BE58	J328	BE58	LR25	LR25	N265	N265	PAY4	PA42	SW3	SW3	UH1	UH1
F16	F16	GL25	N265	JCOM	BE58	LR31	LR31	NA1	BE58	PAYE	PAYE	SW39	SW3	UH60	UH60
F16C	F16	GLF2	N265	JS20	BA46	LR35	LR35	NA4	BE58	PAZT	PAZT	SW4	SW4	UNK	BE58
F18	F18	GLF3	N265	JS31	BA46	LR36	LR35	NEWX	NEWX	PC12	AC69	T1	T1	V35B	BE58
F20	BE58	GLF4	N265	JS32	BA46	LR45	LR35	NIM	BE58	PC6	AC69	T114	BE58	VC10	BE58
F24	FA28	GLF5	N265	JS41	BA46	LR55	LR55	P180	C421	PC6P	AC69	T134	T34	WA42	BE58
F26	FA28	GOLF	N265	JST	BA46	LR60	LR60	P210	PA34	PC6T	AC69	T154	TU5	WB57	BE58
F260	FA28	GULF	N265	JSTA	BA46	M020	MO20	P28	BA31	PC7	AC69	T2	T2	WL	BE58
F27	FA27	GY80	N265	JSTB	BA31	M02J	MO20	P28A	BA31	PC9	BE58	T20	T2	WW1	BE58
F28	FA28	H1	DH8	JSTR	BA46	M1F	M1F	P28B	BA31	PL12	BE58	T204	T2	WW2	WW24
F2TH	BE58	H25	BE58	K35A	KC35	M20	M1F	P28R	BA31	PROP	BE58	T210	T2	WW23	WW24
F33	FA28	H25A	HS25	K35E	KC35	M201	M1F	P28T	BA31	PUMA	BE58	T303	T34	WW24	WW24
F4	F18	H25B	HS25	K35R	KC35	M20C	M1F	P3	P3	R100	BE58	T31T	T34	WWP	WW24
F406	BE58	H25C	HS25	KC10	B707	M20F	M1F	P31	G159	R300	BE58	T33	C23	Y42	YK4
F50	N265	H46	C23	KC13	KC35	M20J	M1F	P31P	G159	R90R	BE58	T34	T34	YK18	YK4
F60	FK70	H47	BE20	KC35	KC35	M20K	M1F	P31T	G159	RALL	BE58	T34P	T34	YK4	YK4
F70	FK70	H53	BE20	KE35	KE35	M20M	M1F	P32	PA32	RC12	BE58	T34T	T34	YK40	YK4
F90	BE30	H53E	BE20	KR35	KR35	M20P	M1F	P32R	PA32	RV6	BE58	T37	T37	YK42	YK4
F900	BE30	H57	AJ25	L101	L1011	M20R	M1F	P32T	PA32	S05R	S20	T38	T38I	YN7	BE58
FA02	FA27	H60	BE20	L180	L188	M20T	M1F	P34	PA34	S2	S20	T38I	T38I	YS11	YS11
FA10	FA28	H64	BE20	L188	L188	M339	M1F	P3C	P3	S20	S20	T39	T38I	Z42	B73S
FA18	F18	H65	BE20	L1F	L1F	MD11	MD11	P42	PA42	S226	S20	T44	T34	ZZZZ	B73S
FA20	FA27	HAR	A4	L200	LR35	MD80	MD88	P66T	PA60	S3	AJ25	T45	F18		
FA22	FA27	HB2	BE58	L235	LR35	MD82	MD88	P68	PA60	S360	S20	T6	T37		
FA27	FA27	HB25	BE58	L24	LR24	MD83	MD88	P808	PA60	S601	S20	T700	BE58		
FA28	FA28	HC25	HS25	L24J	LR24	MD87	MD88	PA16	PA23	S61	S20	TA4	TA4		
FA30	BE58	HC5	BE58	L29A	CL60	MD88	MD88	PA22	PA23	S65	S20	TA42	TA4		
FA50	FA27	HDC8	BE58	L29B	CL60	MD90	MD88	PA23	PA23	S65C	BE58	TAMP	TA4		
FA90	BE30	HELO	BE58	L329	L329	MF17	M1F	PA24	PA24	S76	C560	TB10	BE58		
FAF	FA27	HERN	BE58	L382	L382	MG29	F18	PA25	PA24	SA20	BE58	TB20	BE58		
FD90	BE58	HF20	BE58	L39	L382	MH53	M1F	PA27	PA28	SA27	BE58	TB21	BE58		
FFJ	FFJ	HH60	AJ25	L40	LR60	MIR2	F18	PA28	PA28	SB20	BE58	TB30	BE58		
FJ20	N265	HK17	BE58	L410	LR60	ML7	BE58	PA30	PA30	SBR	BE58	TB40	BE58		
FJ50	BE58	HM17	BE58	L4T	LR60	MO2	MO20	PA31	PA31	SBR1	FA27	TB7	BE58		
FK10	FK10	HOT	BE58	L60	LR60	MO20	MO20	PA32	PA32	SBRI	FA27	TB70	BE58		
FK27	FA27	HPR7	BE58	LJ23	LR24	MO21	MO20	PA34	PA34	SC7	BE58	TBM	BE58		
FK28	FA27	HS25	HS25	LJ24	LR24	MO2J	MO20	PA38	PA34	SD3	BE58	TBM7	BE58		
FK50	N265	HS28	HS25	LJ25	LR31	MO2K	MO20	PA39	PA34	SF20	S20	TC12	BE58		
FK70	FK70	HS45	HS25	LJ26	LR25	MRC	A10	PA41	PA41	SF34	SF34	TEST	BE58		
G1	G2	HS74	N265	LJ28	LR35	MRF1	A10	PA42	PA42	SH3	AJ25	TOBA	BE58		

G.3 DESCRIPTION OF THE MODEL

This section gives an overall description of all components of the parametric model. Each parameter is then discussed in detail in the following sections.

Input demand is composed of the four variables below for each city pairs. This can be one average day's demand (operational data), which can be used to estimate the entire year's demand.

Arrival airport	Departure airport	Aircraft type	Number of flights
j_a	j_d	t_j	n_j

The model will estimate the taxi-out and arrival delay changes due to differences in capacities and demands. See section G.9 for detailed descriptions.

Total fuel burn for both the baseline and optimal scenarios are calculated as follows. The baseline scenario has no CNS/ATM measures, and the optimal scenario has expected CNS/ATM measures:

Baseline:

$$TFBB\ ?\ \underset{j}{?}\ Ib_j\ ?\ Gdb_j\ ?\ T_j\ ?\ C_j\ ?\ Rb_j\ ?\ A_j\ ?\ Adb_j$$

Optimal:

$$TFBO\ ?\ \underset{j}{?}\ Io_j\ ?\ Gdo_j\ ?\ T_j\ ?\ C_j\ ?\ Ro_j\ ?\ A_j\ ?\ Ado_j$$

Where:

$TFBB$ =Total Fuel burn, baseline scenario
$TFBO$ = Total fuel burn, optimal scenario
n_j = Number of flights for city pair j
j = City pair ($j.a$, $j.d$) where $j.a$ is the origin and $j.d$ is the destination
Ib_j = Unimpeded idle phase for the baseline scenario (without CNS/ATM measures) forcity pair j
Io_j = Idle phase for the optimal scenario (with CNS/ATM measures) for city pair j
Gdb_j = Ground delay for the baseline scenario for city pair j
Gdo_j = Ground delay for optimal scenario for city pair j
T_j = Take-off phase for city pair j
C_j = Climb phase (less than 3,000) for city pair j
A_j = Unimpeded approach phase for city pair j
Rb_j = Baseline cruise phase for city pair j
Ro_j = Optimal cruise phase for city pair j

Adb_j = Arrival delay for baseline case for city pair *j*
Ado_j = Arrival delay for optimal case for city pair *j*

The above calculation shows the difference between the baseline and optimal scenarios to be in ground delay, approach delay, unimpeded idle and, finally, cruise fuel burn.

The average arrival delay for the optimal case, Ado_j, is average arrival delay for baseline times a percent change due to capacity or demand increase/decrease. The percent change is calculated using methodology described in section G.9.

For comparison purposes, we kept all the assumptions for CNS/ATM initiatives as well as demand and capacity the same as the 1998 simulation study and recalculated fuel savings for all years using our parametric model. The results are close to 1998 U.S. study. We then changed the demand for baseline year from 1996 to 1999 and adjusted all future demands and recalculated the fuel savings using the parametric model.

As this methodology suggests, the primary parameters are the growth rate of the demand, changes in airport capacity, and therefore changes in arrival and ground delays, and estimated improvements in flight time due to CNS/ATM initiatives.

G.4 SURFACE

Fuel burn for the “unimpeded idle” phase is calculated by the formulas below. The unimpeded times may vary between the baseline and optimal scenarios (e.g., certain CNS/ATM initiatives such as ADS-B may reduce taxi-times by as much as 5%).

Baseline scenario:

$$Ib_j = \sum_t (Tib_j + Tob_j) \cdot F_t \cdot n_{tj}$$

Optimal scenario:

$$Io_j = \sum_t (Tio_j + Too_j) \cdot F_t \cdot n_{tj}$$

Where:
Ib_j = Idle phase for the baseline scenario (without CNS/ATM measures) for city pair *j*
Io_j = Idle phase for the optimal scenario (with CNS/ATM measures) for city pair *j*
n_{tj} = Number of flights for city pair *j* and aircraft type *t*
j = City pair (j_o, j_d) where $j.a$ is the origin and $j.d$ is the destination
F_t =ICAO’s fuel burn rate per minute for aircraft type *t*
Tob_j = Unimpeded taxi-out time at departing airport j_d, baseline scenario
Tib_j = Unimpeded taxi-in time at arrival airport j_o, baseline scenario
Too_j = Unimpeded taxi-out time at departing airport j_d, optimal scenario
Tio_j = Unimpeded taxi-in time at arrival airport j_o, optimal scenario

Table G.4-1 lists unimpeded taxi-in and taxi-out times, Tob_j and Tib_j, and estimated surface delays (see Section G.9) for some sample U.S. and Europe airports. Table G.4-2 lists fuel burn rates F_t, for some sample aircraft types.

Table G.4-1. Unimpeded Taxi times and estimated Surface Delay For Some Sample U.S. and European Airports

Airport	Unimpeded Taxi-In (mins)	Unimpeded Taxi-out (mins)	Surface Delay for 1999 (mins)
ABQ	4.93	9.18	0.53
AUS	3.16	8.47	0.69
BOS	5.02	11.69	9.36
DCA	3.78	9.73	3.57
DEN	5.31	11.08	0.42
DFW	4.77	9.87	1.75
DTW	4.49	10.29	2.87
ELP	2.59	7.33	0.30
EWR	5.67	11.76	4.86
JAX	4.26	8.82	0.21
JFK	6.32	16.37	7.46
LAS	3.90	11.38	0.63
LAX	5.62	10.79	3.48
MCO	4.84	11.57	0.95
MDW	3.81	8.77	2.94
MEM	3.56	8.29	3.77
SAN	2.65	10.47	1.36
SAT	2.71	8.11	0.80
SDF	3.16	7.67	0.61
SFO	4.51	11.13	2.08
EBBR	5.92	13.75	2.83
EDDB	5.92	12.50	2.83
EDDF	8.42	15.25	1.65
EDDH	4.79	7.50	3.25
EDDK	5.00	8.75	4.25

Airport	Unimpeded Taxi-In (mins)	Unimpeded Taxi-out (mins)	Surface Delay for 1999 (mins)
EDDL	4.10	11.50	1.66
EDDM	5.53	17.00	0.29
EDDS	5.92	9.00	0.09
EDDT	5.92	13.00	0.18
EDDV	5.62	5.50	3.51
EDDW	4.00	3.50	5.50
EGJJ	6.10	8.50	1.38
EHAM	3.50	15.00	0.81
EIDW	14.00	9.00	1.00
EPWA	4.99	6.75	4.63
HECA	5.00	15.00	1.04
LDZA	5.98	7.00	4.67
LEBL	5.92	12.00	3.56
LEMD	7.55	12.25	4.29
LEMG	4.44	11.50	1.88
LFKB	3.00	6.00	0.60
LIML	5.92	13.00	1.00
LJLJ	3.97	7.00	5.18
LOWW	5.92	13.00	2.65
LPFR	5.92	12.00	0.94
LPFU	5.92	12.00	1.67
LPPT	5.92	11.50	4.20
LSZH	5.92	12.00	4.22
LTBA	5.92	12.25	4.02

Table G.4-2. Surface Fuel Burn Per Minute (Aircraft Data for Surface (idle) Phase)

		Emissions Coefficients (kg/1000kg Fuel)		
Known Aircraft Type	Fuel Rate (kg/min)	HC	CO	NOx
A10	2.88	20.04	58.6	2.82
A300	24.59	1.48	18.89	4.76
A310	18.00	6.28	28.2	3.4
A320	12.13	1.4	17.6	4
A4	1.44	20.04	58.6	2.82
A6	2.88	20.04	58.6	2.82
AA5	0.06	49.2	897.4	1.16
AC50	0.12	49.2	897.4	1.16
AC69	2.60	22	66	2.9
AJ25	2.88	20.04	58.6	2.82
ARJ	5.95	3.95	42.6	3.82
AT42	4.80	0	14.9	5.7
B1	32.39	112	98	25
B52	64.78	112	98	25
B707	32.39	112	98	25
B727-200	26.58	1.46	11	3.2
B73S	13.68	2.28	34.4	3.9
B747-200	56.86	12	53	3
B74F	49.91	1.92	21.86	4.8
B74R	49.91	1.92	21.86	4.8
B757-200	22.79	1	15.44	4.3
B767-200	18.00	6.29	28.2	3.4
B777	29.03	2.7	18.7	4.4
BA11	14.28	56.73	97.96	1.48
BA14	14.28	56.73	97.96	1.48
BA31	2.60	22	66	2.9
BA41	2.60	22	66	2.9
BA46	9.79	5.39	40.93	3.78
BATP	2.60	22	66	2.9
BE02	2.60	22	66	2.9
BE10	0.12	49.2	897.4	1.16
BE18	0.06	29	644.4	1.58
BE20	0.12	49.2	897.4	1.16
BE30	2.60	22	66	2.9
BE33	0.06	49.2	897.4	1.16
BE35	0.06	29	644.4	1.58
BE36	0.06	49.2	897.4	1.16
BE3B	2.60	22	66	2.9
BE40	7.68	18	155	0.9
BE55	0.12	49.2	897.4	1.16
BE58	0.12	49.2	897.4	1.16
BE60	0.12	49.2	897.4	1.16
BE76	0.12	49.2	897.4	1.16
BE8T	0.12	49.2	897.4	1.16
BE90	0.12	49.2	897.4	1.16
BE99	0.12	49.2	897.4	1.16
BN2	0.12	49.2	897.4	1.16
C12	2.48	3.4	21	4
C130	18.45	17.61	43.6	3.52
C141	25.58	91.96	88.5	1.77
C152	0.06	29	644.4	1.58

G.5 BELOW 3,000 FEET

The total fuel burn for take-off, climb (up to 3,000 feet), and unimpeded approach for each city pairs are calculated as follows. We assumed that no variation exists between the optimal and baseline scenarios for these phases of flight.

Take-off:

$$T_j = \sum_t T_t \times FT_t \times n_{tj}$$

Climb:

$$C_j = \sum_t C_t \times FC_t \times n_{tj}$$

Unimpeded Approach:

$$A_j = \sum_t A_t \times FA_t \times n_{tj}$$

Where:

T_j = Take-off phase for city pair j

C_j = Climb phase (less than 3,000) for city pair j

A_j = Unimpeded approach phase for city pair j

n_{tj} = Number of flights for city pair j and aircraft type t

T_t =The larger of median take-off time for aircraft type t and .7 minutes

C_t = The larger of median climb (up to 3,000 feet) time for aircraft type t and 2.2 minutes

A_t = The larger of median unimpeded approach time for aircraft type t and 4 minutes

FT_t = ICAO's fuel burn rate for take-off for aircraft type t [12]

FC_t = ICAO's fuel burn rate for climb (up to 3,000 feet) for aircraft type t [12]

FA_t = ICAO's fuel burn rate for unimpeded approach for aircraft type t [12]

Tables G.5-1, G.5-2, and G.5-3 list fuel burn rates, (FA_t, FC_t, and FT_t) and emissions coefficients for some sample aircraft type and approach, initial climb, and take-off phase of flights, respectively. These are obtained by mapping engines from the ICAO Engine Exhaust Emissions Data Bank to the proper aircraft types.

Tables G.5-4, G.5-5, and G.5-6 list initial climb, take-off, and unimpeded approach times, respectively for some sample aircraft types. These statistics are obtained from simulation outputs in FAA [1]. ICAO's default values of .7, 2.2, and 4 minutes for take-off, climb, and approach, respectively, were used whenever the simulation median was smaller.

Table G.5-1. Approach Phase of Flight (Below 3,000 Feet)

		Emissions Coefficients (kg/1000kg Fuel)			
Known Aircraft	Fuel (kg/min/engine)	HC	CO	NOx	# of Engines
A300	0.305	0.11	1.91	12.53	2
A320	0.132	0.4	2.5	8	2
AT42	0.032	0	6	8.1	2
B727-200	0.154	0.55	2.77	6.9	3
B73S	0.132	0.08	3.8	8.3	2
B757-200	0.259	0.04	1.71	7.5	2
B767-200	0.279	0.47	3.1	10.3	2
B777	0.397	0.2	0.4	12	2
BA14	0.127	7.23	20.3	7.94	2
BA41	0.018	3.8	21.8	4.5	2
BATP	0.018	3.8	21.8	4.5	2
BE02	0.018	3.8	21.8	4.5	2
BE20	0.002	9.7	691.3	10.1	2
BE36	0.002	9.7	691.3	10.1	1
BE55	0.002	9.7	691.3	10.1	2
BE58	0.002	9.7	691.3	10.1	2
BE90	0.002	9.7	691.3	10.1	2
C172	0.001	0.033	1187.8	1.14	1
C182	0.001	0.033	1187.8	1.14	1
C210	0.001	0.033	1187.8	1.14	1
C310	0.002	9.7	691.3	10.1	2
C340	0.002	9.7	691.3	10.1	2
C414	0.002	9.7	691.3	10.1	2
C421	0.002	9.7	691.3	10.1	2
C500	0.056	2.7	88	1.5	2
C550	0.054	0.13	1.9	6.86	2
C560	0.054	0.13	1.9	6.86	2
CRJ	0.054	0.13	1.9	6.86	2
D328	0.032	0	6	8.1	2
DC86	0.130	0.4	2.2	6.3	4
DC9-50	0.161	1.96	2.7	8	2
DH8	0.032	0	6	8.1	2
E120	0.027	0	6.5	7.9	2
F16	0.171	0.6	3	11	2
FA28	0.101	6.97	22.22	5.92	2
FK10	0.104	0.9	3.9	5.7	2
HS25	0.054	0.13	1.9	6.86	2
LR35	0.030	4.26	22.38	5.9	2
MD88	0.174	1.6	4.2	9.1	2
MO20	0.002	9.7	691.3	10.1	1
PA28	0.001	0.03322	1187.8	1.14	1
PA31	0.018	0	4.8	6.2	2
PA32	0.002	9.7	691.3	10.1	1
PA34	0.002	9.7	691.3	10.1	2
PA60	0.002	9.7	691.3	10.1	2

Table G.5-2. Climb Phase of Flight (Below 3,000 Feet)

		Emissions Coefficients (kg/1000kg Fuel)			
Known Aircraft	Fuel (kg/min/engine)	HC	CO	NOx	# of Engines
A300	0.951	0.05	0.04	21.69	2
A320	0.391	0.23	0.9	19.6	2
AT42	0.050	0	2.3	12.3	2
B727-200	0.429	0.28	1.15	15.1	3
B73S	0.359	0.05	0.95	15.5	2
B757-200	0.685	0.01	1.23	36.2	2
B767-200	0.814	0.29	1.1	25.6	2
B777	1.220	0.1	0.1	35.5	2
BA14	0.329	1.32	2.06	19.18	2
BA41	0.032	0	6.4	6.6	2
BATP	0.032	0	6.4	6.6	2
BE02	0.032	0	6.4	6.6	2
BE20	0.004	8.16	983.3	4.59	2
BE36	0.004	8.16	983.3	4.59	1
BE55	0.004	8.16	983.3	4.59	2
BE58	0.004	8.16	983.3	4.59	2
BE90	0.004	8.16	983.3	4.59	2
C172	0.003	20.81	974.1	4.87	1
C182	0.003	20.81	974.1	4.87	1
C210	0.003	20.81	974.1	4.87	1
C310	0.004	8.16	983.3	4.59	2
C340	0.004	8.16	983.3	4.59	2
C414	0.004	8.16	983.3	4.59	2
C421	0.004	8.16	983.3	4.59	2
C500	0.139	0.2	27	3.7	2
C550	0.152	0.06	0	10.14	2
C560	0.152	0.06	0	10.14	2
CRJ	0.152	0.06	0	10.14	2
D328	0.050	0	2.3	12.3	2
DC86	0.368	0.25	1.1	14	4
DC9-50	0.452	0.27	1.1	15.7	2
DH8	0.050	0	2.3	12.3	2
E120	0.050	0	2.4	12	2
F16	0.594	0.05	1.8	44	2
FA28	0.267	0.16	0	14.64	2
FK10	0.286	0.3	0.8	16.8	2
HS25	0.152	0.06	0	10.14	2
LR35	0.078	0.128	2.03	13.08	2
MD88	0.489	0.43	1.2	20.6	2
MO20	0.004	8.16	983.3	4.59	1
PA28	0.003	20.81	974.1	4.87	1
PA31	0.032	0	0.94	9	2
PA32	0.004	8.16	983.3	4.59	1
PA34	0.004	8.16	983.3	4.59	2
PA60	0.004	8.16	983.3	4.59	2

Table G.5-3. Take-Off Phase of Flight (Below 3,000 Feet)

		Emissions Coefficients (kg/1000kg Fuel)			
Known Aircraft	Fuel (kg/min/engine)	HC	CO	NOx	# of Engines
A300	1.170	0.04	0.06	28.57	2
A320	0.477	0.23	0.9	24.6	2
AT42	0.059	0	2	13.8	2
B727-200	0.534	0.241	0.03	19.4	3
B73S	0.429	0.04	0.9	17.7	2
B757-200	0.844	0.04	1.01	52.7	2
B767-200	0.973	0.29	1	29.8	2
B777	1.547	0.1	0.1	45	2
BA14	0.403	0.98	1.81	23.27	2
BA41	0.036	0	4.7	7	2
BATP	0.036	0	4.7	7	2
BE02	0.036	0	4.7	7	2
BE20	0.006	10	199	1.99	2
BE36	0.006	10	199	1.99	1
BE55	0.006	10	199	1.99	2
BE58	0.006	10	199	1.99	2
BE90	0.006	10	199	1.99	2
C172	0.003	20.81	974.1	4.87	1
C182	0.003	20.81	974.1	4.87	1
C210	0.003	20.81	974.1	4.87	1
C310	0.006	10	199	1.99	2
C340	0.006	10	199	1.99	2
C414	0.006	10	199	1.99	2
C421	0.006	10	199	1.99	2
C500	0.159	0.1	27	4.2	2
C550	0.185	0.06	0	11.61	2
C560	0.185	0.06	0	11.61	2
CRJ	0.185	0.06	0	11.61	2
D328	0.059	0	2	13.8	2
DC86	0.449	0.25	0.9	17.2	4
DC9-50	0.565	0.22	0.9	20.6	2
DH8	0.059	0	2	13.8	2
E120	0.054	0	2.2	12.7	2
F16	2.526	0.1	55.1	16.5	2
FA28	0.327	0.88	0.44	18.92	2
FK10	0.345	0.8	0.7	21.1	2
HS25	0.185	0.06	0	11.61	2
LR35	0.093	0.114	1.39	15.25	2
MD88	0.599	0.28	0.8	25.7	2
MO20	0.006	10	199	1.99	1
PA28	0.003	20.81	974.1	4.87	1
PA31	0.036	0	0.71	9.7	2
PA32	0.006	10	199	1.99	1
PA34	0.006	10	199	1.99	2
PA60	0.006	10	199	1.99	2

Table G.5-4. Climb Phase of Flight (Below 3,000 Feet)

AC TYPE	AVG_TIME (mins)	MED_TIME (mins)	LOW_TIME (mins)	HIGH_TIME (mins)
A300	0.66	0.57	0.46	0.89
A320	0.70	0.62	0.51	0.96
AT42	2.38	1.90	1.82	3.34
B727-200	0.66	0.57	0.35	1.15
B73S	0.62	0.54	0.43	0.84
B757-200	0.64	0.56	0.45	0.87
B767-200	0.71	0.57	0.45	1.03
B777	13.03	2.44	1.96	4.42
BA14	2.59	2.04	1.95	3.63
BA41	2.58	2.05	1.96	3.54
BATP	2.44	1.78	1.68	3.69
BE02	2.21	1.75	1.68	3.19
BE20	1.03	0.90	0.43	1.43
BE36	3.88	2.50	1.33	6.65
BE55	3.73	2.67	1.33	6.00
BE58	3.74	2.33	1.11	5.29
BE90	1.33	1.17	0.58	1.85
C172	8.46	5.00	2.15	13.55
C182	5.04	3.25	1.60	7.13
C210	3.64	2.67	1.30	4.90
C310	3.64	2.53	1.54	5.53
C340	2.12	1.69	0.75	3.00
C414	2.10	1.82	0.80	2.75
C421	2.51	1.95	0.66	3.33
C500	2.01	0.72	0.30	2.42
C550	0.73	0.68	0.34	1.05
C560	0.70	0.65	0.31	0.95
CRJ	2.21	2.04	1.92	2.64
D328	2.47	1.90	1.83	3.36
DC86	2.06	1.28	1.19	2.14
DC9-50	0.69	0.60	0.48	0.93
DH8	2.16	1.70	1.62	2.98
E120	2.11	1.72	1.43	3.07
F16	1.48	0.50	0.17	1.03
FA28	2.60	2.49	2.43	2.71
FK10	1.38	1.20	1.12	1.85
HS25	0.71	0.67	0.31	1.08
LR35	0.60	0.59	0.26	0.86
MD88	0.67	0.59	0.48	0.91
MO20	4.90	2.74	1.20	9.14
PA28	6.74	4.00	1.76	11.50
PA31	3.73	2.35	1.18	6.50
PA32	6.11	3.60	1.70	10.60
PA34	4.40	3.20	1.38	7.40
PA60	3.07	2.70	1.39	4.45

Table G.5-5. Take-Off Phase of Flight (Below 3,000 Feet)

AC TYPE	AVG_TIME (mins)	MED_TIME (mins)	LOW_TIME (mins)	HIGH_TIME (mins)
A300	0.36	0.28	0.22	0.53
A320	0.40	0.31	0.25	0.54
AT42	2.89	3.12	1.24	4.12
B727-200	0.36	0.29	0.15	0.62
B73S	0.33	0.27	0.21	0.48
B757-200	0.34	0.28	0.22	0.50
B767-200	0.37	0.28	0.22	0.56
B777	6.60	1.36	1.01	2.24
BA14	2.90	3.00	1.33	4.19
BA41	2.82	2.72	1.31	4.19
BATP	2.89	3.35	1.27	4.05
BE02	2.88	3.33	1.21	4.04
BE20	0.51	0.45	0.21	0.71
BE36	1.91	1.23	0.66	3.00
BE55	2.41	1.58	0.66	4.48
BE58	1.81	1.15	0.51	2.50
BE90	0.66	0.58	0.29	0.92
C172	3.69	2.26	1.06	6.03
C182	2.44	1.63	0.76	3.43
C210	1.83	1.33	0.64	2.45
C310	2.61	1.80	0.78	4.77
C340	1.06	0.83	0.37	1.50
C414	1.03	0.87	0.40	1.35
C421	1.25	0.97	0.33	1.67
C500	0.92	0.35	0.14	1.20
C550	0.36	0.34	0.17	0.52
C560	0.35	0.32	0.15	0.47
CRJ	1.25	1.16	0.85	1.68
D328	2.72	2.82	1.16	4.09
DC86	1.19	0.77	0.55	1.50

AC TYPE	AVG_TIME (mins)	MED_TIME (mins)	LOW_TIME (mins)	HIGH_TIME (mins)
DC9-50	0.38	0.30	0.23	0.53
DH8	2.81	3.23	1.17	4.00
E120	2.45	2.47	0.97	3.83
F16	0.74	0.25	0.08	0.51
FA28	1.68	1.50	1.07	2.36
FK10	0.84	0.73	0.53	1.20
HS25	0.36	0.33	0.15	0.53
LR35	0.30	0.29	0.13	0.43
MD88	0.37	0.30	0.23	0.56
MO20	2.46	1.35	0.56	4.70
PA28	3.02	2.00	0.83	5.00
PA31	1.90	1.17	0.59	3.25
PA32	2.91	1.80	0.83	5.00
PA34	1.96	1.56	0.66	3.00
PA60	2.15	1.76	0.75	3.96

Table G.5-6. Approach Without delay Phase of Flight (Below 3,000 Feet)

AC TYPE	AVG_TIME (mins)	MED_TIME (mins)	LOW_TIME (mins)	HIGH_TIME (mins)
A300	1.41	1.17	0.05	3.33
A320	1.92	1.53	0.47	4.42
AT42	19.57	17.29	7.77	33.19
B727-200	4.88	2.68	1.11	7.10
B73S	2.00	1.51	0.62	3.57
B757-200	1.77	1.33	0.34	3.48
B767-200	2.31	1.51	0.47	5.14
B777	12.76	12.21	5.69	20.66
BA14	18.26	16.09	7.00	32.18
BA41	15.74	12.63	5.29	29.02
BATP	19.15	17.19	7.79	32.92
BE02	17.58	15.23	6.33	31.17
BE20	5.90	5.10	2.12	9.50
BE36	10.76	9.57	3.60	16.13
BE55	13.06	10.79	3.67	22.70
BE58	10.80	9.38	4.50	17.00
BE90	6.90	5.63	2.62	11.84
C172	13.84	10.50	3.60	23.97
C182	13.44	11.34	4.50	20.45
C210	10.52	9.21	3.00	17.16
C310	16.24	13.28	5.81	28.57
C340	7.57	6.38	2.00	13.50
C414	7.31	6.00	2.25	11.84
C421	8.52	7.64	3.75	13.51
C500	7.20	5.00	2.29	12.00
C550	5.47	4.67	1.90	8.82
C560	5.24	4.58	1.93	8.23
CRJ	10.39	9.49	5.05	16.69
D328	17.50	15.02	6.12	30.35
DC86	14.45	12.33	6.60	23.65

AC TYPE	AVG_TIME (mins)	MED_TIME (mins)	LOW_TIME (mins)	HIGH_TIME (mins)
DC9-50	2.73	1.84	0.73	5.95
DH8	17.14	14.22	6.20	31.57
E120	15.88	12.71	5.12	29.75
F16	6.46	4.09	1.38	10.38
FA28	13.70	12.71	7.34	21.48
FK10	13.30	12.34	6.93	20.90
HS25	6.91	5.01	2.05	10.00
LR35	5.34	4.41	2.00	8.73
MD88	1.68	1.30	0.40	3.32
MO20	11.16	9.14	2.57	18.62
PA28	14.12	11.40	3.60	22.99
PA31	10.80	10.25	3.60	16.89
PA32	13.04	11.41	4.50	19.80
PA34	10.92	8.46	3.60	20.04
PA60	14.56	11.70	4.06	25.68
PAYE	5.61	4.91	2.00	8.96

G.6 CRUISE - ABOVE 3,000 FEET

In order to calculate the cruise time per aircraft type, we first used airport latitude and longitude to calculate the great circle distance for all city pairs. For the U.S., median, low, and high fuel consumption per minute flown for each aircraft type was calculated combining both the baseline and optimal scenarios. The cruise time per great circle mile, however, was calculated separately for these scenarios. The simulation results show that for almost all city pairs, the cruise time decreases for the optimal scenario compared to the baseline. Thus, in our model, for every future year, the percent reduction in the time per great circle mile provides a useful parameter to estimate the savings due to CNS/ATM initiatives (e.g., conflict probe or direct route) that shorten the overall cruise time. Since the flight distances are shorter for intra-Europe and domestic European flights, we repeated the above analysis for all U.S. flights between city pairs less than 500 miles apart and estimated a different fuel burn rate per minute and time per great circle distance rate for optimal scenarios. For the baseline scenario, we used European simulation inputs to calculate the median time per great circle distance.

Fuel burn for cruise is given in the following equation. Fuel rate per minute remains the same for optimal and baseline case. Travel time per great circle distance will vary under baseline and optimal cases and for different CNS/ATM initiatives. As expected, median travel time per great circle distance will go down as routes become more optimal.

Baseline:

$$Rb_j = \sum_t MRb_t \times FR_t \times GC_j \times n_{tj}$$

Optimal:

$$Ro_j = \sum_t MRo_t \times FR_t \times GC_j \times n_{tj}$$

Where:

Rb_j = Baseline cruise phase for city pair *j*

Ro_j = Optimal cruise phase for city pair *j*

MRb_j =Median travel time per great circle distance for baseline case

MRo_j =Median travel time per great circle distance for optimal case

R_t =Median fuel rate per minute for cruise phase and aircraft type *t*

GC_j =Great Circle distance for city pair *i*

n_{tj} = Total number of flights for city pair *j* and aircraft type *t*

Table G.6-1 lists fuel burn rate per minute, R_t, statistics obtained from FAA simulation results in the FAA study [1] for some sample aircraft types. These values were used for calculating fuel burns in the U.S. and global portions. Table G.6-2 lists time per great circle distance, MRb_i, statistics for baseline scenario, and some sample aircraft types. Table G.6-3 lists time per great circle distance, MRo_i, statistics for the optimal scenario in the year 2015 and for some sample aircraft types.

The FAA simulation [1] captures flight portions over CONUS airspace. Since no information was available on exact location (latitude and longitude) of point entries into the CONUS airspace for flight with non-CONUS origin or destination airports in our simulation output [1], the above method of calculating travel time per great circle mile does not apply. Thus, in order to estimate cruise time inside CONUS for such flights, an average cruise time within U.S. airspace is used. This time differs between the optimized and baseline scenarios. For the baseline, 67 minutes of cruise time occurs inside the CONUS on average. This changes to an average of 61 minutes of time in the optimized scenario.

Additionally, U.S. flight data shows flights that originate and arrive at the same location. Clearly, these flights have zero cruise distance. For these flights, the average flight time for all "circular" flights is used. Flight times of 91 and 82 minutes are used for the baseline and optimized scenarios, respectively.

Table G.6-1. Cruise Phase of Flight (Fuel Burn Rate)

AC TYPE	Average (kg/min)	Median (kg/min)	Low Rank (kg/min)	High (kg/min)
A300	84.10	82.65	78.65	88.32
A320	38.92	36.93	34.40	47.22
AT42	10.78	10.71	10.39	11.15
B727-200	63.29	61.13	57.89	70.22
B73S	35.90	34.82	32.34	39.53
B757-200	56.44	54.39	51.78	59.76
B767-200	64.93	62.39	57.28	71.44
B777	156.73	154.60	148.97	165.36
BA14	4.71	4.67	4.50	4.93
BA41	7.38	7.29	7.07	7.67
BATP	15.50	15.38	14.77	16.23
BE02	5.09	5.05	4.88	5.28
BE20	3.77	3.77	3.46	4.02
BE36	1.08	1.08	1.05	1.12
BE55	1.52	1.51	1.46	1.58
BE58	1.61	1.60	1.55	1.67
BE90	2.79	2.80	2.59	2.95
C172	0.66	0.65	0.63	0.68
C182	0.76	0.75	0.73	0.78
C210	0.87	0.86	0.83	0.91
C310	1.43	1.42	1.38	1.49
C340	1.80	1.78	1.72	1.88
C414	2.03	2.02	1.92	2.13
C421	2.02	2.03	1.91	2.12
C500	10.85	2.93	2.39	12.73
C550	4.49	4.52	4.06	4.81
C560	4.66	4.70	4.21	4.98
CRJ	14.20	14.24	13.86	14.51
D328	9.29	9.21	8.96	9.55
DC86	96.08	95.95	92.36	99.68
DC9-50	45.13	43.38	40.49	49.22
DH8	10.19	10.09	9.72	10.61
E120	7.80	7.69	7.46	8.10
F16	9.38	9.24	7.80	10.67
FA28	19.07	19.12	18.62	19.44
FK10	27.93	28.05	27.11	28.64
HS25	6.11	6.16	5.60	6.55
LR35	5.33	5.39	4.87	5.72
MD88	44.31	43.35	40.73	47.10
MO20	0.77	0.77	0.74	0.79
PA28	0.90	0.89	0.86	0.92
PA31	2.12	2.11	2.04	2.19
PA32	1.06	1.06	1.03	1.09
PA34	1.25	1.23	1.20	1.29
PA60	1.65	1.65	1.58	1.72

Table G.6-2. Cruise: Time per Great Circle Mile (GCM) For U.S. and Globe (Case: Baseline Year 2015)

AC TYPE	Average (mins/GCM)	Median (mins/GCM)	Low Rank (mins/GCM)	High Rank (mins/GCM)
A300	0.152	0.150	0.137	0.168
A320	0.153	0.153	0.137	0.170
AT42	0.257	0.266	0.198	0.320
B727-200	0.151	0.152	0.136	0.167
B73S	0.158	0.158	0.141	0.174
B757-200	0.154	0.154	0.136	0.170
B767-200	0.153	0.153	0.134	0.168
B777	0.166	0.164	0.145	0.182
BA14	0.263	0.270	0.202	0.328
BA41	0.269	0.278	0.218	0.329
BATP	0.267	0.279	0.196	0.342
BE02	0.263	0.272	0.206	0.326
BE20	0.258	0.260	0.218	0.303
BE36	0.329	0.338	0.273	0.386
BE55	0.286	0.294	0.220	0.346
BE58	0.281	0.294	0.213	0.338
BE90	0.291	0.292	0.247	0.339
C172	0.419	0.434	0.273	0.561
C182	0.388	0.400	0.315	0.468
C210	0.331	0.347	0.272	0.395
C310	0.273	0.284	0.197	0.337
C340	0.301	0.321	0.232	0.365
C414	0.298	0.315	0.246	0.358
C421	0.304	0.316	0.247	0.359
C500	0.215	0.186	0.119	0.325
C550	0.218	0.212	0.182	0.256
C560	0.205	0.199	0.165	0.245
CRJ	0.189	0.186	0.161	0.219
D328	0.257	0.263	0.196	0.315
DC86	0.173	0.169	0.143	0.203
DC9-50	0.156	0.157	0.139	0.173
DH8	0.274	0.282	0.220	0.337
E120	0.272	0.280	0.220	0.336
F16	0.230	0.182	0.115	0.361
FA28	0.179	0.180	0.157	0.203
FK10	0.187	0.183	0.159	0.215
HS25	0.197	0.187	0.154	0.242
LR35	0.186	0.176	0.149	0.230
MD88	0.159	0.158	0.142	0.174
MO20	0.335	0.354	0.265	0.415
PA28	0.403	0.423	0.267	0.510
PA31	0.288	0.305	0.226	0.351
PA32	0.346	0.357	0.262	0.425
PA34	0.326	0.334	0.238	0.399
PA60	0.263	0.275	0.194	0.326

Table G.6-3. Cruise: Time per Great Circle Mile (GCM) For U.S. and Globe (Case: Optimal Year 2015

AC TYPE	Average (mins/GCM)	Median (mins/GCM)	Low Rank (mins/GCM)	High Rank (mins/GCM)
A300	0.147	0.148	0.135	0.158
A320	0.155	0.156	0.139	0.170
AT42	0.225	0.238	0.140	0.290
B727-200	0.148	0.143	0.133	0.163
B73S	0.156	0.155	0.139	0.170
B757-200	0.151	0.149	0.134	0.166
B767-200	0.150	0.150	0.134	0.165
B777	0.163	0.156	0.136	0.176
BA14	0.216	0.231	0.118	0.293
BA41	0.211	0.224	0.129	0.287
BATP	0.214	0.228	0.120	0.291
BE02	0.220	0.229	0.129	0.289
BE20	0.230	0.236	0.197	0.268
BE36	0.316	0.326	0.249	0.366
BE55	0.274	0.281	0.191	0.337
BE58	0.265	0.281	0.203	0.318
BE90	0.264	0.269	0.220	0.309
C172	0.386	0.410	0.234	0.512
C182	0.370	0.383	0.288	0.455
C210	0.312	0.324	0.251	0.378
C310	0.264	0.274	0.188	0.322
C340	0.280	0.300	0.211	0.343
C414	0.286	0.297	0.242	0.334
C421	0.283	0.294	0.236	0.333
C500	0.211	0.192	0.109	0.315
C550	0.194	0.194	0.168	0.227
C560	0.177	0.176	0.148	0.211
CRJ	0.168	0.169	0.145	0.187
D328	0.235	0.244	0.156	0.293
DC86	0.160	0.157	0.140	0.172
DC9-50	0.155	0.155	0.138	0.169
DH8	0.220	0.233	0.127	0.297
E120	0.223	0.237	0.138	0.291
F16	0.188	0.158	0.086	0.248
FA28	0.163	0.161	0.138	0.173
FK10	0.162	0.161	0.141	0.176
HS25	0.180	0.173	0.150	0.214
LR35	0.167	0.161	0.140	0.195
MD88	0.156	0.155	0.140	0.170
MO20	0.315	0.334	0.231	0.396
PA28	0.382	0.401	0.255	0.482
PA31	0.271	0.289	0.216	0.330
PA32	0.329	0.336	0.243	0.404
PA34	0.312	0.315	0.243	0.389
PA60	0.256	0.268	0.167	0.318

G.7 EMISSIONS CALCULATIONS

For below 3,000 feet and surface phase of flight, emissions, CO, NOx, and HC calculations are done by simply multiplying the emission coefficients obtained from "ICAO Engine Exhaust Emissions Data Bank" to total fuel burns.

Above 3,000 feet, we used the simulation results in the FAA [1] to calculate median, low and high emission coefficients per aircraft type that were summed over all city pairs. These coefficients change for different altitude. Since the altitude and trajectory for a given city pair vary between baseline and optimal scenarios, these statistics were calculated separately for each scenario and for the years 1999, 2005, 2010, and 2015.

Table G.7-1 lists NOx, CO, and HC coefficients for the baseline scenario and some sample aircraft types. Table G.7-2 lists NOx, CO, and HC coefficients for the 2005 optimal scenario and some sample aircraft types. It should be noted that the results obtained for NOx, CO, and HC are preliminary and subject to further analysis, verification and validation.

Table G.7-1 & 2. Emissions Coefficient, Calculated Using Simulation Results [1]

Table G.7-1: Baseline Scenario

	Emissions Coefficients (kg/1000kg Fuel)		
AC Type	NOx	CO	HC
A300	18.61	10.55	4.43
A320	13.78	5.66	0.64
AT42	13.08	4.30	0.00
B727-200	10.31	3.69	0.61
B73S	11.53	12.33	1.02
B757-200	16.23	7.81	0.67
B767-200	15.71	4.94	1.06
B777	12.00	0.40	0.20
BA14	11.38	12.65	1.59
BA41	8.19	4.02	0.20
BATP	8.20	4.00	0.20
BE02	8.19	4.00	0.19
BE20	10.09	691.30	9.69
BE36	10.07	691.30	9.67
BE55	10.08	691.30	9.68
BE58	10.08	691.30	9.68
BE90	10.08	691.30	9.69
C172	1.09	1187.80	0.03
C182	1.10	1187.80	0.03
C210	1.10	1187.80	0.03
C310	10.07	691.30	9.67
C340	10.08	691.30	9.68
C414	10.08	691.30	9.68
C421	10.08	691.30	9.68
C500	10.40	5.25	0.48
C550	6.85	1.89	0.12
C560	6.85	1.89	0.12
CRJ	6.86	1.90	0.13
D328	11.80	5.10	0.60
DC86	6.49	28.98	22.95
DC9-50	10.44	5.34	0.74
DH8	11.80	5.10	0.60
E120	8.10	4.00	0.19
F16	11.00	3.00	0.60
FA28	10.37	5.70	0.49
FK10	10.82	13.39	1.93
HS25	6.85	1.89	0.12
LR35	9.72	3.50	0.44
MD88	13.81	5.20	1.53
MO20	10.05	691.30	9.65
PA28	1.10	1187.80	0.03
PA31	12.28	5.08	0.58
PA32	10.07	691.30	9.67
PA34	10.07	691.30	9.67
PA60	10.08	691.30	9.68

Table G.7-2: Optimized Scenario for 2005

	Emissions Coefficients (kg/1000kg Fuel)		
AC Type	NOx	CO	HC
A300	17.70	8.02	3.48
A320	13.23	4.95	0.61
AT42	13.08	4.30	0.00
B727-200	10.31	3.69	0.61
B73S	11.18	10.61	0.87
B757-200	15.34	7.07	0.58
B767-200	15.68	4.92	1.05
B777	12.00	0.40	0.20
BA14	11.37	12.60	1.58
BA41	8.19	4.01	0.20
BATP	8.20	4.00	0.20
BE02	8.18	4.00	0.19
BE20	10.09	691.30	9.69
BE36	10.07	691.30	9.67
BE55	10.08	691.30	9.68
BE58	10.08	691.30	9.68
BE90	10.08	691.30	9.68
C172	1.09	1187.80	0.03
C182	1.10	1187.80	0.03
C210	1.10	1187.80	0.03
C310	10.07	691.30	9.67
C340	10.08	691.30	9.68
C414	10.08	691.30	9.68
C421	10.08	691.30	9.68
C500	10.31	4.73	0.47
C550	6.85	1.89	0.12
C560	6.85	1.89	0.12
CRJ	6.85	1.89	0.12
D328	11.77	5.10	0.59
DC86	6.46	28.37	22.35
DC9-50	10.30	4.92	0.71
DH8	11.78	5.10	0.59
E120	8.09	4.00	0.19
F16	11.00	3.00	0.60
FA28	10.13	5.18	0.48
FK10	10.43	12.00	1.81
HS25	6.85	1.89	0.12
LR35	9.66	3.37	0.44
MD88	13.08	4.87	1.48
MO20	10.05	691.30	9.65
PA28	1.10	1187.80	0.03
PA31	12.28	5.08	0.58
PA32	10.07	691.30	9.67
PA34	10.07	691.30	9.67
PA60	10.08	691.30	9.68

G.8 ADJUSTING FOR FLEET MIX

Aircraft engine improvements as well as fleet mix changes over time can influence the fuel burn. As aircraft are retired and replacements are purchased, newer models tend to have improved fuel usage and reduced emissions.

The parametric model uses the FESG assumptions regarding reduced emissions and fuel usage due to engine improvements. FESG assumes that this reduction is 1% a year over the next 20 years amounting to 20% overall reduction.

G.9 AIRPORT GROUND AND ARRIVAL DELAY

G.9.1 Parametric Model

The fuel burn calculations for ground delays are similar to surface calculations.

Baseline scenario:

$$Gdb_j \; ? \; \underset{t}{?} \; G_j \, ? F_t \, ? n_{tj} \, ? Delb_j$$

Optimal scenario:

$$Gdo_j \; ? \; \underset{t}{?} \; G_j \, ? F_t \, ? n_{tj} \, ? Delo_j$$

Gdb_j = Ground delay for the baseline scenario for city pair j

Gdo_j = Ground delay for optimal scenario for city pair j

G_j = Ground delay (taxi-in and taxi-out) associated with city pair j for simulation year

n_{tj} = Number of flights for city pair j and aircraft type t

j = City pair (j_o,j_d) where j_o is the origin and j_d is the destination

F_t = Median fuel burn rate, idle phase, per minute for aircraft type t

$Delb_j$ = Delay factor for the baseline case, obtained from the ratio described in subsection

$Delo_j$ = Delay factor for the baseline case, obtained from the ratio described in subsection

Similarly, fuel burn for delays at arrival airport are calculated as follows:

Baseline scenario:

$$Adb_j \; ? \; \underset{t}{?} \; A_j \, ? FA_t \, ? n_{tj} \, ? Delb_j$$

Optimal scenario:

$$Ado_j \; ? \; \underset{t}{?} \; A_j \, ? FA_t \, ? n_{tj} \, ? Delo_j$$

Adb_j = Arrival delay for baseline case for arrival airport associated with city pair j

Ado_j = Arrival delay for optimal case for arrival airport associated with city pair j

A_j = Average delay at the arrival airport associated with city pair *j* from simulation

n_{tj} = Number of flights for city pair *j* and aircraft type *t*

$Delb_{jy}$ = Delay factor for the baseline case (year *y*), obtained from the ratio described in section G.9.2

$Dela_y$ = Delay factor for the optimal case (year *y*), obtained from the ratio described in section G.9.2

FA_t = ICAO's fuel burn rate for unimpeded approach for aircraft type *t* [12]

G.9.2 Delay, Capacity, and Demand Relationships

Changes in both capacity and demand will have impact on ground and delay at arrival airports. It is assumed that delay occurs in congested or constrained airports. For the U.S., we have identified 80 such airports [5]. For Europe there exists 25 or more such airports (see Table G.9.2-1). Furthermore, AEA [15] identifies 27 airports that have had significant arrival delays (see Table G.12.2-1).

A queueing theory approximation estimates the percent changes in delays due to capacity or demand changes. The capacity is the average VFR and IFR capacity at the airport and is estimated as described in Section G.10. Steady-state queueing theory is used to establish a relationship between these so that one can estimate the other. It is a sufficiently accurate approximation and a Rough-Order-of-Magnitude (ROM) estimate.

Approximate delay reduction using *G*/*G*/1 (general arrival and service distributions queue with First-In First-Out (FIFO) discipline is assumed. Detailed information on *G/G/1* queueing model is available in [17]. Assumptions such as FIFO discipline or one server (runway) per airport are made in most NAS-wide simulation models such as NAS Performance Analysis Capability (NASPAC), or Detailed Policy Assessment Tool (DPAT), and several other studies. In any *G*/*G*/1 queue, an upper bound on average delay is calculated as:

$$Delay \; ? \; \frac{?(?_A^2 \; ? \; ?_B^2)}{2(1 \; ? \; ?/?)}$$

$?$ = Arrival/departure rate (demand)

$?$ = Airport capacity

$?_A^2$? Variance of inter-arrival/departure time

$?_B^2$? Variance of service time (i.e., time to land the aircraft and clear the runway)

As seen in the above formula, delay is inversely and nonlinearly correlated with capacity. To calculate the delay factors, we have assumed that the variances of inter-arrival (departure) and service times remain constant for all the years under study (1999-2015). The delay factors, $Delb_{jy}$ and $Delo_{jy}$, are calculated then as:

$$Delb_{jy} = \frac{D_{jy}}{D_{jx}} \cdot \left(\frac{1 - D_{jx}/CAP_{jx}}{1 - D_{jy}/CAPb_{jy}} \right)$$

$$Delo_{jy} = \frac{D_{jy}}{D_{jx}} \cdot \left(\frac{1 - D_{jx}/CAP_{jx}}{1 - D_{jy}/CAPo_{jy}} \right)$$

Where:

CAP_{jx} = Average capacity at arrival (departure) airport *j.a (j.d)* for the year that delay information exists

$CAPb_{jy}$ = Average capacity for the baseline case, at arrival (departure) airport *j.a (j.d)* for the year that adjustment ratio is calculated

$CAPo_{jy}$ = Average capacity for the optimal case, at arrival (departure) airport *j.a (j.d)* for the year that adjustment ratio is calculated

D_{jy} = Demand at arrival (departure) airport *j.a (j.d)* for the year that delay information exists

D_{jx} = Demand at arrival (departure) airport *j.a (j.d)* for the year that adjustment ratio is calculated

Table G.9.2-1. European Current and Future Airports,
Y = Constrained (Congested) N = Not Constrained (Congested)

ICAO_ CODE	Country	City	1998	2005	2010	ICAO_ CODE	Country	City	1998	2005	2010
LOWS	AUSTRIA	Salzburg	Y	Y	Y	LIRN	ITALY	Naples	N	N	N
LOWS	AUSTRIA	Salzburg	Y	Y	Y	LIRQ	ITALY	FLORENCE	N	N	N
LOWW	AUSTRIA	Vienna	N	N	N	EVRA	LATVIA	Riga	N	N	N
EBBR	BELGIUM	Brussels	N	Y	N	EYVI	LITHUANIA	Vilnius	N	N	N
LBSF	BULGARIA	Sofia	N	N	N	ELLX	LUXEMBOURG	Luxembourg	N	N	N
LDZA	CROATIA	Zagreb	N	N	N	LMML	MALTA	Valleta	N	N	N
LCLK	CYPRUS	Larnaca	N	N	N	ENBR	NORWAY	Bergen	N	N	N
LKPR	CZECH REPUBLIC	Prague	N	N	N	ENFB	NORWAY	Oslo - Fornebu	N	N	N
EKBI	DENMARK	Billund	N	N	N	ENGM	NORWAY	Oslo	N	N	N
EKCH	DENMARK	Copenhagen	N	N	N	ENZV	NORWAY	Stavanger	N	N	N
EETN	ESTONIA	Tallinn	N	N	N	EPWA	POLAND	Warsaw	Y	N	N
EFHK	FINLAND	Helsinki	N	N	N	LPFR	PORTUGAL	Faro	Y	Y	N
LFBD	FRANCE	Bordeaux	N	N	N	LPFU	PORTUGAL	Porto Santo	Y	N	N
LFBO	FRANCE	Toulouse	N	N	N	LPPR	PORTUGAL	Porto	Y	N	N
LFKJ	FRANCE	Ajaccio	N	N	N	LPPT	PORTUGAL	Lisboa	N	N	Y
LFLC	FRANCE	Clermont-Ferrand	Y	N	N	LROP	ROMANIA	Bucharest	N	N	N
LFLL	FRANCE	Lyon	N	N	N	LZIB	SLOVAK REPUBLIC	Bratislava	N	N	N
LFML	FRANCE	Marseille	Y	N	N	LJLJ	SLOVENIA	Ljubljana	N	N	N
LFMN	FRANCE	Nice	N	N	N	GCFV	SPAIN	Puerto del Rosario	N	N	N
LFMT	FRANCE	Montpellier	N	N	N	GCLP	SPAIN	Las Palmas - Gran Canaria	N	N	N
LFPB	FRANCE	Paris	N	N	N	GCRR	SPAIN	Arrecife	N	N	N
LFPG	FRANCE	Paris	N	N	N	GCTS	SPAIN	Tenerife Sur	Y	N	N
LFPO	FRANCE	Paris	N	N	N	LEAL	SPAIN	Alicante	N	N	N
LFQQ	FRANCE	Lille	N	N	N	LEBL	SPAIN	Barcelona	N	N	N
LFRN	FRANCE	Rennes	N	N	N	LEGE	SPAIN	Gerona	N	N	N
LFRS	FRANCE	Nantes	N	N	Y	LEIB	SPAIN	Ibiza	N	N	N
LFSB	FRANCE	Bale-Mulhouse	Y	Y	Y	LEMD	SPAIN	Madrid	N	N	N
LFST	FRANCE	Strasbourg	N	N	N	LEMG	SPAIN	Malaga	N	N	N
EDDB	GERMANY	Berlin	N	N	N	LEMH	SPAIN	Mahon	N	N	N
EDDC	GERMANY	Dresden	N	N	N	LEPA	SPAIN	Palma de Mallorca	N	N	N
EDDE	GERMANY	Erfurt	N	N	N	LEZL	SPAIN	Sevilla	N	N	N
EDDF	GERMANY	Frankfurt / Main	Y	N	N	ESGG	SWEDEN	Gothenburg	Y	N	N
EDDH	GERMANY	Hamburg	N	N	N	ESMS	SWEDEN	Malmo	Y	Y	Y
EDDI	GERMANY	Berlin	N	N	N	ESSA	SWEDEN	Stockholm	N	N	N
EDDK	GERMANY	Koln	N	N	N	ESSB	SWEDEN	Stockholm	Y	Y	Y
EDDL	GERMANY	Dusseldorf	Y	Y	Y	LSGG	SWITZERLAND	Geneva	N	N	N
EDDM	GERMANY	Munich	N	N	N	LSZH	SWITZERLAND	Zurich	N	N	N
EDDN	GERMANY	Nurnberg	N	N	N	EHAM	THE NETHERLANDS	Amsterdam	Y	Y	Y
EDDP	GERMANY	Leipzig - Halle	N	N	N	EHBK	THE NETHERLANDS	Maastricht	Y	N	N
EDDS	GERMANY	Stuttgart	N	Y	N	EHGG	THE NETHERLANDS	Groningen	N	N	N
EDDT	GERMANY	Berlin	N	N	N	EHRD	THE NETHERLANDS	Rotterdam	N	N	N
EDDV	GERMANY	Hannover	N	N	N	EGAA	UNITED KINGDOM	Belfast	N	N	N
EDDW	GERMANY	Bremen	N	N	N	EGAC	UNITED KINGDOM	Belfast	N	N	N
LGAT	GREECE	Athens	N	N	N	EGBB	UNITED KINGDOM	Birmingham	N	N	N
LGIR	GREECE	Heraklion	N	N	N	EGCC	UNITED KINGDOM	Manchester	Y	Y	Y
LGKO	GREECE	Kos	Y	N	N	EGGW	UNITED KINGDOM	London	N	Y	Y
LGKR	GREECE	Corfu	N	N	N	EGHI	UNITED KINGDOM	Southampton	N	N	N
LGRP	GREECE	Rhodes	N	N	N	EGJB	UNITED KINGDOM	St Peter Port	N	N	N
LGTS	GREECE	Thessaloniki	N	N	N	EGJJ	UNITED KINGDOM	Jersey	N	N	N
LHBP	HUNGARY	Budapest	N	N	N	EGKK	UNITED KINGDOM	London	N	N	N
BIKF	ICELAND	Reykjavik	N	N	N	EGLL	UNITED KINGDOM	London	Y	Y	Y
EIDW	IRELAND	Dublin	N	N	N	EGNM	UNITED KINGDOM	Leeds	N	N	N
EINN	IRELAND	Limerick	N	N	N	EGNT	UNITED KINGDOM	Newcastle Upon Tyne	N	N	N
LIMC	ITALY	Milan	N	N	N	EGNX	UNITED KINGDOM	Derby, Nottingham, Leicester	N	N	N
LIMF	ITALY	Turin	N	N	N	EGPD	UNITED KINGDOM	Aberdeen	N	N	N
LIML	ITALY	Milan	N	N	N	EGPF	UNITED KINGDOM	Glasgow	N	N	N
LIPZ	ITALY	Venice	Y	N	N	EGPH	UNITED KINGDOM	Edinburgh	N	N	N
LIRF	ITALY	Rome	N	Y	N	EGSS	UNITED KINGDOM	London	Y	N	N

G.10 AIRPORT CAPACITY

To estimate delay at a constrained airport, we need to know the demand and capacities at such airports. Since airport capacity drops during IFR conditions, we first calculate the overall capacity for such airports.

The average capacity for an airport is:

$$CAP_{jx} \ ? \ VC_{jx} \ ? \ prob(VC_j) \ ? \ IC_{jx} \ ? \ prob(IC_j)$$

Where:

CAP_{jy}	= Average capacity at airport $j.a$ or $j.d$ and year x
VC_{jy}	= VFR capacity at airport $j.a$ or $j.d$ and year x
IC_{jy}	= IFR capacity at airport $j.a$ or $j.d$ and year x
$Prob(VC_j)$	= Likelihood of VFR condition at airport $j.a$ or $j.d$
$Prob(IC_j)$	= Likelihood of IFR condition at airport $j.a$ or $j.d$

The likelihood of VFR and IFR conditions is calculated for all airports using a 40-year summary of NCDC surface weather data [4]. When we could not find an airport in the NCDC database, the closest airport geographically was used. The list of substituted airports in Europe is provided in Table G.10-1. For European airports, no IFR capacities were available, so it is assumed that IFR capacity is 68% of VFR capacity. The 68% is based on the U.S. median. The U.S. IFR and VFR capacities are taken from 80 U.S. airports [5]. This reference also provides percentage increase in maximum arrival rates for some CNS/ATM measures. For Europe, it is assumed that CNS/ATM technologies will increase 50/50 capacities for constrained airports. The percentage increase is shown in Table 4.1-1. Table G.9.2-1 contains the list of constrained airports, as provided by EUROCONTROL.

Table G.10-1. Airport Weather Conditions Mapping for Missing European Airports

Airport with missing weather info	City	Airport	Weather is mapped to	City	Airport
EDDC	Dresden	Dresden	EDDB	Berlin	Berlin-Schonefeld
EDDI	Berlin	Berlin Tempelhof	EDDB	Berlin	Berlin-Schonefeld
EDDL	Dusseldorf	Dusseldorf International	EDDB	Berlin	Berlin-Schonefeld
EDDN	Nurnberg	Flughafen Nurnberg	EDDS	Stuttgart	Stuttgart Airport
EDDP	Leipzig - Halle	Flughafen Leipzig - Halle	EDDH	Hamburg	Hamburg-Fuhlsbuettel
EDDT	Berlin	Berlin Tegel	EDDB	Berlin	Berlin-Schonefeld
EDDV	Hannover	Hannover	EDDH	Hamburg	Hamburg-Fuhlsbuettel
EGGW	London	London - Luton	EGKK	London	London - Gatwick
EGNX	Derby, Nottingham, Leicester	East Midlands Airport	EGBB	Birminghar	Birmingham International Airport
EGSS	London	London - Stansted	EDDK	Koln	Koln/Bonn
EHBK	Maastricht	Maastricht - Aachen	EDDK	Koln	Koln/Bonn
ESSB	Stockholm	Stockholm-Bromma Airport	ESSA	Stockholm	Stockholm - Arlanda
GCFV	Puerto del Rosario	Fuerteventura	GCLP	Las Palma	Las Palmas - Gran Canaria
GCRR	Arrecife	Lanzarote-Arrecife	GCLP	Las Palma	Las Palmas - Gran Canaria
LDZA	Zagreb	Zagreb Airport	LJLJ	Ljubljana	Ljubljana Airport
LEGE	Gerona	Gerona	LEMD	Madrid	Madrid - Barajas
LFBO	Toulouse	Toulouse - Blagnac	LFBD	Bordeaux	Bordeaux - Merignac
LFLC	Clermont-Ferrand	Clermont-Ferrand/Auvergne	LFLL	Lyon	Lyon - Satolas
LFMT	Montpellier	Montpellier Mediterranee	LFMN	Nice	Nice Cote d'Azur
LFPB	Paris	Paris - Le Bourget	LFPO	Paris	Paris - Orly
LFPG	Paris	Paris - Charles De Gaulle	LFPO	Paris	Paris - Orly
LFSB	Bale-Mulhouse	Eurairport Bale-Mulhouse	LFST	Strasbourg	Strasbourg Entzheim
LGIR	Heraklion	Nikos Kazantzakis	LGAT	Athens	Hellinikon
LGKR	Corfu	Kerkyra - I. Kapodistrias	LGAT	Athens	Hellinikon
LIMF	Turin	Turin - Caselle	LIMC	Milan	Milan - Malpensa
LIML	Milan	Milan - Linate	LIMC	Milan	Milan - Malpensa
LOWS	Salzburg	Salzburg Airport W.A. Mozart	EDDM	Munich	Munich Franz- Josef Straub

G.11 OCEANIC FUEL USAGE

At this time, we have estimated the fuel usage due to oceanic flights without the related emissions. The total fuel burn for an oceanic flight is based on the 1998 U.S. CNS/ATM Emissions Study combined with the FESG forecast of oceanic flights. The study assumed that all flights would be affected by the planned CNS/ATM improvements. Currently, the planned improvements are limited to North Atlantic flights.

Oceanic fuel usage is estimated by multiplying the average fuel usage per flight for a baseline (unimproved) flight by the number of flights, with the improvement only on the North Atlantic portion. The fuel usage per flight is estimated to be 93,150 lbs. without improvements. The CNS/ATM improvements reduce fuel consumption by 1.6% by 2007, per Table G.11-1. This table also shows the breakdown of flights for the North Atlantic, as well as the rest of the world, with a summary of the results.

Table G.11-1. Oceanic Fuel Usage and Demand

	Demand		Fuel Usage	ATM/CNS Savings	Fuel Usage
Year	North Atlantic	Global	Baseline		Optimized
1998	**806**	**1,418**	**60,511**	**0.1%**	**60,477**
1999	**832**	**1,460**	**61,682**	**0.2%**	**61,612**
2000	**863**	**1,521**	**63,629**	**0.5%**	**63,448**
2001	**895**	**1,584**	**65,603**	**0.8%**	**65,307**
2002	**930**	**1,659**	**67,984**	**1.0%**	**67,603**
2003	**966**	**1,741**	**70,616**	**1.2%**	**70,145**
2004	**1,003**	**1,825**	**73,258**	**1.4%**	**72,694**
2005	**1,041**	**1,910**	**75,850**	**1.6%**	**75,188**
2006	**1,080**	**1,998**	**78,502**	**1.6%**	**77,823**
2007	**1,120**	**2,090**	**81,228**	**1.6%**	**80,531**
2008	**1,157**	**2,167**	**83,306**	**1.6%**	**82,594**
2009	**1,192**	**2,243**	**85,305**	**1.6%**	**84,580**
2010	**1,228**	**2,322**	**87,305**	**1.6%**	**86,566**
2011	**1,261**	**2,397**	**89,114**	**1.6%**	**88,363**
2012	**1,295**	**2,475**	**90,968**	**1.6%**	**90,206**
2013	**1,331**	**2,557**	**92,919**	**1.6%**	**92,145**
2014	**1,369**	**2,646**	**95,037**	**1.6%**	**94,250**
2015	**1,410**	**2,742**	**97,332**	**1.6%**	**96,531**

G.12 EUROPEAN SEGMENT

This section includes all additional steps as well as calibrations that are done in the Parametric Model for Europe.

G.12.1 Assumptions

All additional assumptions for Europe are listed in this portion as follows:

While calculating delay at arrival airport, we assumed that departure delay (gate delay), that is the difference between actual departure and scheduled departure, is 7.5 minutes for all European airports not listed in AEA [15].

Taxi-out delays for European airports are estimated as the difference between taxi-out times provided by the Airlines to EUROCONTROL and taxi-out times used in the EUROCONTROL AMOC simulation model.

G.12.2 Estimating Delay at Arrival Airports for Europe

This portion describes the methodology used to extract air delays occurring due to congestion at arrival airport as noted in the AEA reports.

The AEA publishes summaries of departure and arrival delays of over 15 minutes in their "Punctuality Report" where arrival (departure) delay is defined as the difference between scheduled arrival (departure) time and actual arrival (departure) time whenever the difference is greater than 15 minutes. As shown in Table G.12.2-1, these reports provide average delays and percentage of delayed flights. In columns 7 and 8 of this table,"% arr (dep) flights delayed over

15 minutes ” and average arrival and “departure delays for all delayed flights over 15 minutes” are multiplied to obtain an overall average of arrival or departure delay per flight.

Since the arrival delay contains departure and taxi-out delays, we used the following methodology to estimate the air delays. We extracted intra-Europe flights from our European demands and estimated the air delays for 25 European airports as:

$$A_j^{EU} \ ? \ \begin{matrix} ? AD_{j.d} \ ? \ DD_{ji.a} \ ? \ TO_{i.a} & \qquad AD_{j.d} \ ? \ DD_{j.a} \ ? \ TO_{j.a} \ ? \ 0 \\ ? 0 & \qquad \mathit{Otherwise} \end{matrix}$$

Where:

$AD_{j.d}$ =Arrival delays at destination airport (*j.d)* taken from Table 12, and 0 for all other European airports.

$DD_{j.o}$ =Departure delays at destination airport (*j.d)* taken from Table 12, and 7.5 for all other European airports. We have assumed that all the European airports not listed in AEA reports have an average of 7.5 minutes gate delays.

$TO_{j.o}$ =Taxi–out delay extracted from our model for all European airports

Table G.12.2-2 illustrates these estimated averages.

Table G.12.2-1. Arrival and Departure Delays, Summary for 1999

City	Airport	% Dep Flights Delayed over 15 minutes	Avg Dep Delay (mins) for all delayed flights over 15 minutes	% Arr Flights Delayed over 15 minutes	Avg Arr Delay (mins) for all delayed flights over 15 minutes	Avg Dep Delay (mins)	Avg Arr Delay (mins)
Amsterdam	**EHAM**	**30.3**	**39.3**	**22.9**	**45**	**11.9**	**10.3**
Athens	**LGAT**	**36.6**	**46**	**44.1**	**50.7**	**16.8**	**22.4**
Barcelona	**LEBL**	**47.9**	**49.4**	**47.9**	**51.1**	**23.7**	**24.5**
Brussels	**EBBR**	**35.4**	**38.8**	**34.1**	**42.2**	**13.7**	**14.4**
Copenhagen	**EKCH**	**18.3**	**40.4**	**19.7**	**40.2**	**7.4**	**7.9**
Dublin	**EIDW**	**19.8**	**42**	**25.3**	**42.1**	**8.3**	**10.7**
Dusseldorf	**EDDL**	**23.6**	**39.8**	**28**	**41**	**9.4**	**11.5**
Frankfurt	**EDDF**	**33.5**	**38.8**	**39.7**	**41.1**	**13.0**	**16.3**
Geneva	**LSGG**	**33.7**	**42.2**	**36.4**	**42.3**	**14.2**	**15.4**
Helsinki	**EFHF**	**18.9**	**38.3**	**20.3**	**40.9**	**7.2**	**8.3**
Istanbul	**LTBA**	**30**	**42.9**	**48**	**45.3**	**12.9**	**21.7**
Larnaca	**LCLK**	**24.8**	**59.2**	**38.6**	**59.9**	**14.7**	**23.1**
Lisbon	**LPPT**	**36.3**	**46.4**	**43.1**	**51.3**	**16.8**	**22.1**
London Gatwick	**EGKK**	**20.9**	**37.9**	**27.3**	**48.1**	**7.9**	**13.1**
London Heathrow	**EGLL**	**25.7**	**40.1**	**32.8**	**42.8**	**10.3**	**14.0**
Madrid	**LEMD**	**48.4**	**48.4**	**48.6**	**50.1**	**23.4**	**24.3**
Manchester	**EGCC**	**27.2**	**40.7**	**29.5**	**44.6**	**11.1**	**13.2**
Milan Linate	**LIML**	**31.2**	**43.2**	**36.3**	**49.3**	**13.5**	**17.9**
Milan Malpensa	**LIMC**	**54**	**48.7**	**57.1**	**46**	**26.3**	**26.3**
Munich	**EDDM**	**36.7**	**42.3**	**33.1**	**44.2**	**15.5**	**14.6**
Oslo	**ENGM**	**22.3**	**42.1**	**26.8**	**42.3**	**9.4**	**11.3**
Paris CDG	**LFPG**	**36.4**	**43.2**	**41.3**	**43.5**	**15.7**	**18.0**
Paris Orly	**LFPO**	**30.8**	**46.8**	**38.1**	**44**	**14.4**	**16.8**
Rome	**LIRA**	**37.4**	**43.3**	**40.9**	**45.3**	**16.2**	**18.5**
Stockholm	**ESSA**	**18.5**	**39**	**21.1**	**40.7**	**7.2**	**8.6**
Vienna	**LOWW**	**23.4**	**42.5**	**26.2**	**43**	**9.9**	**11.3**
Zurich	**LSZH**	**32.5**	**42**	**35.7**	**40.5**	**13.7**	**14.5**

Table G.12.2-2. Delay At Arrival Airport, European Airports (Due To Congestion at the Arrival Airport)

City	Airport	# of flights	Avg Holding in the air (min)
BRUSSELS	EBBR	387	3.82
FRANKFURT	EDDF	497	5.22
DUSSELDORF	EDDL	259	1.90
MUNICH	EDDM	383	3.91
HELSINKI	EFHF	1	0.80
MANCHESTER	EGCC	265	3.41
LONDON GATWICK	EGKK	311	3.21
LONDON HEATHROW	EGLL	468	2.94
AMSTERDAM	EHAM	490	1.36
DUBLIN	EIDW	247	1.84
COPENHAGEN	EKCH	324	0.21
OSLO	ENGM	272	2.92
STOCKHOLM	ESSA	279	0.62
LARNACA	LCLK	50	11.17
BARCELONA	LEBL	330	10.35
MADRID	LEMD	392	10.78
Paris CDG	LFPG	532	6.59
Paris ORLY	LFPO	314	6.59
Athens	LGAT	234	12.47
MILAN MALPENSA	LIMC	289	14.95
MILAN LINATE	LIML	126	7.47
ROME	LIRA	46	8.93
VIENNA	LOWW	260	1.78
LISBON	LPPT	151	9.28
GENEVA	LSGG	176	3.87
ZURICH	LSZH	388	3.66
ISTANBUL	LTBA	197	10.38

G.12.3 Cruise

To evaluate the cruise phase of flight in Europe, it was necessary to develop equivalent fuel burn rates, as well as travel time per great circle distance as was done for the U.S. To do this, we used U.S. flights between city pairs within 500 miles distance to calculate fuel burn rate for Europe. This was done because the average flight distances in Europe are considerably shorter than in the U.S. and this is a reasonable approximation.

Table G.12.3-1 lists cruise time per great circle distance and some sample aircraft types. These statistics were obtained using European simulation results.

The data contained in the European simulation had average initial altitudes of greater than 3,000 feet. The FAA model assumes cruise begins at 3,000 feet. In order to correct this difference in data, we estimated the time to climb to be the average climb rates in the U.S. data (e.g., a 6,000-foot climb at 1,000 feet/min results in 6 minutes of additional cruise time). Examination of the data resulted in an overall addition of 6.4 minutes to the cruise time. These 6.4 minutes are added to all flights as additional cruise times in the calculation for European air traffic.

For flights leaving the continental airspace (i.e., non-European destinations or origins) the data, like the U.S., begins or ends at the edge of European airspace. Since the great circle distance is not applicable to these flights, we used the average time the flight remained inside the continental airspace for all flights. This resulted in two values: 1) 120 minutes for the baseline cases, and 2) 110 minutes for the optimized cases. These flight times were used for all non-continental flights.

Table G.12.3-1. Cruise Time per Great Circle Mile (GCM) for Europe

AC Type	Average (mins/GCM)	Median (mins/GCM)	Low Rank (mins/GCM)	High Rank (mins/GCM)
A300	0.148	0.145	0.133	0.163
A320	0.150	0.147	0.134	0.166
AT42	0.274	0.277	0.221	0.329
B727-200	0.148	0.148	0.125	0.175
B73S	0.153	0.151	0.132	0.175
B757-200	0.145	0.144	0.134	0.157
B767-200	0.148	0.145	0.135	0.162
B777	0.166	0.164	0.145	0.182
BE20	0.249	0.237	0.177	0.300
BE36	0.379	0.393	0.304	0.438
BE55	0.344	0.353	0.200	0.465
BE58	0.245	0.211	0.169	0.329
BE90	0.300	0.347	0.152	0.371
C172	0.310	0.281	0.212	0.450
C182	0.283	0.291	0.176	0.334
C210	0.281	0.283	0.168	0.404
C310	0.349	0.356	0.196	0.481
C340	0.386	0.392	0.317	0.454
C414	0.230	0.224	0.196	0.246
C421	0.227	0.235	0.163	0.278
C500	0.177	0.173	0.145	0.204
C550	0.180	0.176	0.153	0.207
C560	0.152	0.144	0.123	0.172
CRJ	0.159	0.157	0.141	0.181
D328	0.231	0.229	0.196	0.263
DC86	0.152	0.144	0.138	0.189
DC9-50	0.168	0.163	0.140	0.199
DH8	0.243	0.241	0.185	0.291
E120	0.230	0.233	0.191	0.273
F16	0.113	0.124	0.066	0.132
FA28	0.174	0.167	0.136	0.205
FK10	0.162	0.160	0.137	0.193
HS25	0.153	0.152	0.134	0.175
LR35	0.188	0.153	0.127	0.180
MD88	0.154	0.150	0.135	0.173
PA28	0.302	0.316	0.204	0.396
PA31	0.254	0.233	0.161	0.356
PA32	0.378	0.406	0.265	0.477
PA34	0.377	0.358	0.250	0.452
PA60	0.338	0.376	0.141	0.449
SF34	0.248	0.248	0.206	0.291

G.13 GLOBAL SEGMENT

The parametric model was used to estimate total fuel consumption and emissions for the entire globe. Since, at present, we have no information on CNS/ATM improvements outside the U.S. and Europe, only the baseline cases were considered. Similarly, we currently have no information on airport capacities and delays outside the U.S. and Europe. Thus, no taxi-out or arrival delays were considered for the baseline cases. The OAG is the only data source available to us that lists scheduled flights for the entire world. The OAG provides information on arrival and departure city pairs and aircraft type.

We took all July 1999 flights from OAG and extracted those flights that originated and ended in the U.S. (CONUS) or EUROPE/ECAC countries. We further removed all flights between the U.S. (CONUS) and Europe/ECAC. The remaining flights were averaged over a one-month period to calculate one day's demand as an input to our parametric model. These flights still contained segments that were counted already in the U.S., European, or Oceanic portions of parametric model. Next, we identified all flights with Oceanic routes and subtracted out their oceanic fuel usage. Similarly, segments of flights that arrived in (left from) U.S. or Europe from (to) the rest of the world are already considered as part of U.S or Europe. Thus, we only consider segments that are not in the U.S. or Europe.

For the cruise phase of flight, we used the U.S. fuel burn rates per aircraft type and chose not to use fuel burn rates calculated from flights between city pairs 500 miles or less apart. This is because most of these flights are as long or even longer than flights within U.S.

Currently, no information exists on airport capacities, taxi-time durations, or delays for airports outside the U.S. and Europe. Thus, we assumed that taxi times are 26 minutes - ICAO's default. We further assumed 2/3 taxi-out and 1/3 taxi-in. No additional delays were assumed.

For approach, take-off, and climb phases of flights (below 3,000 feet), we used the same parameters as for the U.S. and Europe and the same methodology. No arrival delays were considered for these flights.

APPENDIX H:
DESCRIPTION OF THE PARAMETRIC MODEL IMPLEMENTATION

H.1 INTRODUCTION

The parametric model was implemented in a combination of linked Excel™ Spreadsheets and an Access Database. Most calculations are performed in the spreadsheets with the primary inputs and queries to extract and combine the data done in Access™.

H.2 MICROSOFT ACCESS™ DATABASE

The Access Database contains numerous tables of data, queries, macros, modules, and one form. The form is the controlling view with various buttons for modifying selections and then executing the model. Section H.4 contains a view of the screens.

Tables H.2-1 and H.2-2 list the primary Access tables and queries with their corresponding function.

Table H.2-1. Parametric Model Access Database

Table	Description
Emissions Coefficients	**ICAO emissions factors for each AC**
U.S. Demand 99	**CONUS Flights from spreadsheet**
Europe Demand 99	**Flight data for Europe from spreadsheet**
Global Demand 99	**OAG Based Global Flights from spreadsheet**
AC_Map	**Cross Reference mapping from one AC type to AC on which we have data**
Selections	**Linked to Spreadsheet contains input parameters**
AC Time_GC Cruise	**Aircraft Flight Time per Great_Circle mile – Cruise mode, function of Opt, and year – Developed based on U.S. Flights**
AC Time_GC Euro	**Same as above – Developed based on European trajectories for baseline case**
All Flights Fuel by Mode	**Rate of fuel burn/minute for each phase of flight.**
Europe_fuel_cruise	**Cruise phase for Europe;** **Statistics for Fuel burn/minute are based on U.S. flights between city pairs of less than 500 miles Great Circle Distance**
All Flights Fuel by Mode	**Rate of fuel burn/minute for each phase of flight.**
Europe_fuel_cruise	**Cruise phase for Europe;** **Statistics for Fuel burn/minute are based on U.S. flights between city pairs pairs of less than 500 miles Great Circle Distance**
Arrival Delay	**Avg air delay for specific airports in U.S.**
Airports	**List of airports, which includes latitude, longitude and general location (EUROPE, CONUS…)**

Table H.2-2. Parametric Model Access Database (queries)

Queries	Description
Cruise xx (xx= U.S., Europe, Global)	**Detailed fuel estimate for cruise phase of flights**
C_T_A xx	**Same for Climb-out, Take-off and Approach w/o Delay**
Approach Delay	**Air delay for Europe and U.S. only**
Taxi xx	**Same for Taxi/Surface phase**
Totals xx	**Summarizes detailed estimates**

H.3 MICROSOFT EXCEL™ SPREADSHEETS

There are six linked spreadsheets in the model. The sheet "Emissions Inputs" is the controlling sheet with a graphical interface provided to move the user to the selected data location. All parameters are modified/selected and passed back to Access for the results. Section H.4 contains a view of the screens. A description of the spreadsheets is provided in Table H.3-1.

Table H.3-1. Excel Spreadsheets

Spreadsheet	Description
Emissions Input.xls	**Primary user interface (see Figure H-1)**
FESG FORECAST.xls	**Demand data/growth rates supplied by FESG**
Flight1 1999.xls	**Detailed flights for 1999 U.S., EUROPE, and GLOBAL**
TaxiData.xls	**Data on unimpeded taxi times and delay factors for specific airports**
Aircraft_Age.xls	**Provides efficiency increase over time for the fleet via 2 methods**
cap97.xls	**Provides delay factor based on growth and capacities of specific airports**

H.4 INPUT SCREENS

There exist two primary screens with several additional screens where the more detailed parameters can be modified. Below is a short description of the two primary screens.

Figure H.4.4-1 displays the initial screen from Access. Each button represents an Access macro.

“Open Excel Files” causes Excel to be launched and the files listed above to be opened.

“Switch to Excel” allows the user to switch from Access to Excel without re-opening the spreadsheets.

“Create U.S. Totals” all the U.S. related queries to be executed and the results stored in the “Summary Totals” table.

“Create Europe Totals” and “Create Global Totals” perform a similar function to previous item.

“Create Oceanic Totals” executes the queries associated with Oceanic air traffic and places the results in the table “Oceanic Summary.”

“Create All Totals” runs all three Totals functions listed in 3 and 4 above.

“Display Summary Results” simply opens for viewing the “Summary Totals” Table.

“Display Summary Totals” summarizes the “Summary Totals” table and displays the results.

Figure H.4-2 shows the primary input screen in Excel:

“Modify CNS/ATM Initiatives Capacity Factors” takes the user to the screen where detailed parameters that impact airport capacity. Specific examples are given in section H-4 can be modified.

“Modify Fleet Efficiency Factors, ” in combination with the “Fleet Efficiency Method” selection, allows the user to modify the parameters related to fleet efficiency as described in section G.8 above.

“Modify Unimpeded Taxi Times” allows the user to change specific airports unimpeded taxi times due to technological improvements.

“Optimization” selection allows the user to select either Baseline or Optimized. Optimized refers to the implementation of the various CNS/ATM initiatives for the selected year.

“Select Statistical Method” allows the user to evaluate the median, average, low usage with low probability, and high usage with low probability. Whichever statistic is selected causes the Access queries to use the appropriate fuel burn rate results.

“Select Year” allows the user to pick the year of evaluation. Note that only four years are available currently.

“Fleet Efficiency Method” selects the method to use in evaluating increases in fleet efficiency over time. The FESG method uses as simple % increase/year (e.g., 1%). The “Fleet Age” method applies the exponential factor developed by EUROCONTROL using the estimated average age of the fleet as a function of time.

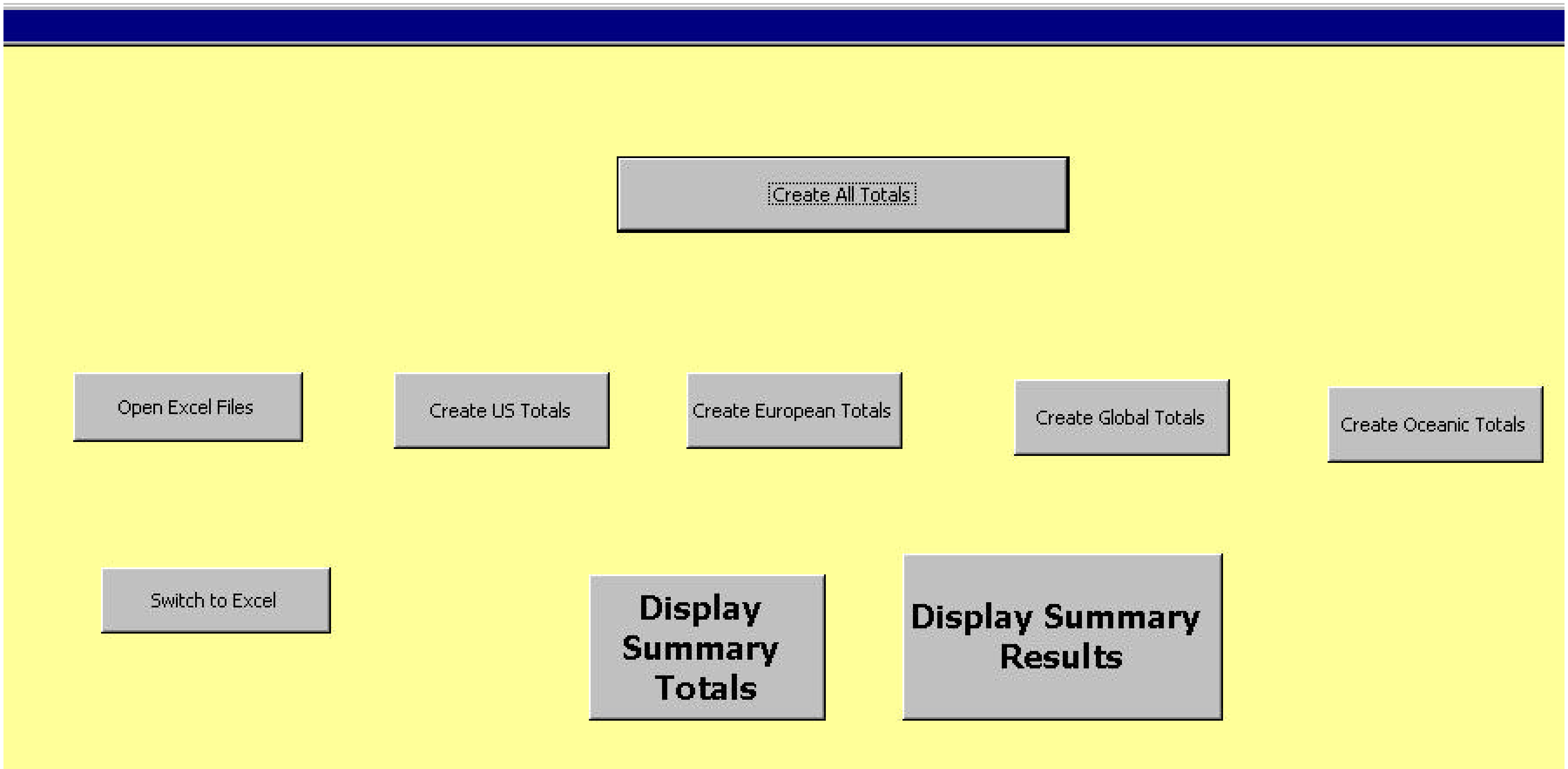

Figure H.4-1. Primary Access User Interface

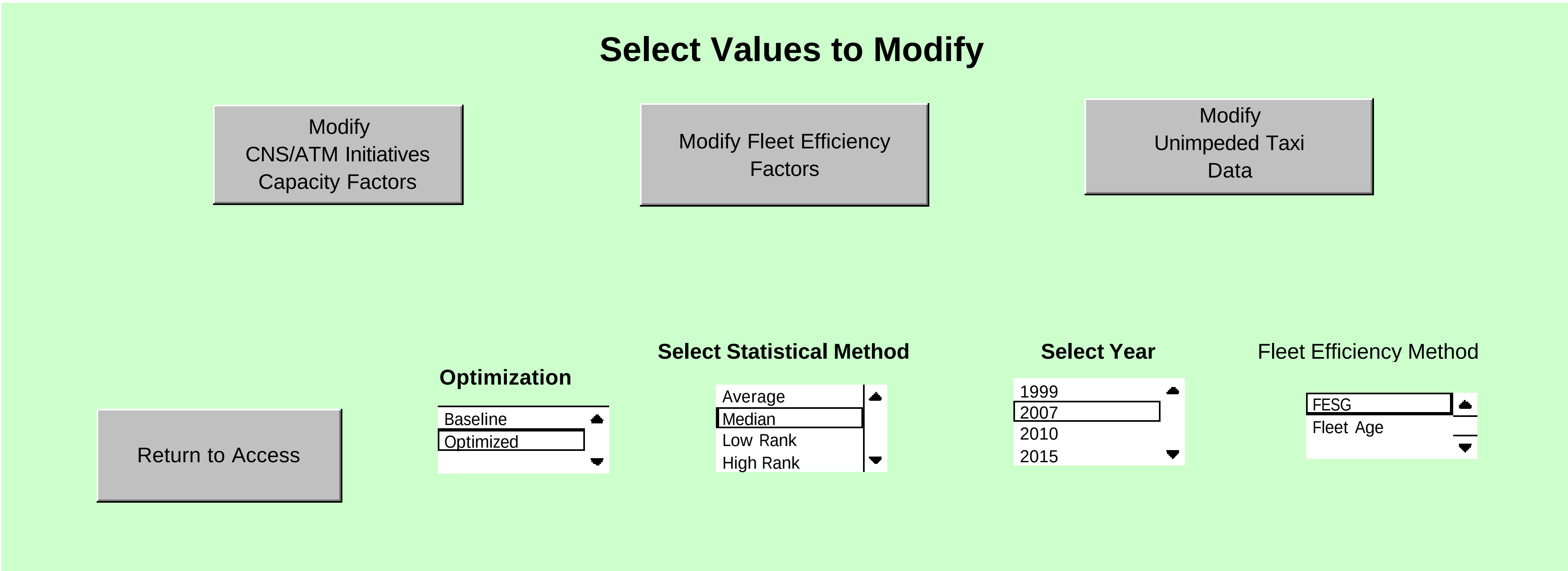

Figure H.4-2. Primary User Interface In Excel

H.5 MODIFIABLE PARAMETERS

Currently, the model permits modification of the impacts of some CNS/ATM initiatives on airport capacities that result in changes in delays. One can also change the year, select statistical variations (e.g. median), baseline scenarios or optimized. In this section, these modifiable parameters are listed and discussed briefly.

The parametric model is designed to estimate fuel consumption levels and changes due to CNS/ATM measures, fleet changes, increased demand and airport capacity changes other than CNS/ATM measures such as additional runways or procedural change. One purpose of this parametric model is to do sensitivity analyses. For example, we might change the demand forecast or change the impact of a CNS/ATM on airport capacity increase to see how the change affects fuel usage.

The other parameters, as shown in Figure H.4-2, are optimization, year, statistic, and fleet efficiency method. Optimization refers to a fuel usage that applies the CNS/ATM measures and optimized flight trajectories versus the baseline scenarios. Year refers to the year of evaluation which affects the fleet efficiency, demand growth factor, and which CNS/ATM initiatives have been implemented. Statistic allows the user to estimate a range for the results. Fleet efficiency method allows the user to choose between the two currently implemented methods for estimating the change in fleet efficiency (fuel and emissions) due to advances in technology and the replacement of older equipment. The FESG method simply applies a flat percentage improvement/year relative to 1999 (e.g., 1% implies a 10% improvement in 2009).

Table H.5-1 summarizes the list of modifiable CNS/ATM initiatives currently available in the parametric model. For a description of the U.S. CNS/ATM initiatives see the FAA [1] or the NAS Architecture web site [16]. The European CNS/ATM initiatives are based on ATM 2000+ documents provided by EUROCONTROL. Table H.5-1 summarizes both U.S. and European CNS/ATM initiatives, time lines, and their impact on en route sectors or airport capacities.

There exist some differences between Europe and U.S. in adjusting the impact of CNS/ATM on airport capacities. For the U.S., the user can modify the default values for increased arrival capacities per runway or reduction in inter-arrival times for 80 airports. For Europe, detailed information per airport was not available. Therefore, the user can modify the percent increase for VFR airport capacity (unless otherwise noted) that will be applied to all constrained European airports.

For the U.S., the user's input usually impacts the maximum arrival rate for IFR or VFR conditions. The parametric model then will calculate the overall capacity (50/50) for IFR and VFR conditions where applicable. For Europe, as mentioned above, the user's input will change the VFR capacity of the airports.

Table H.5-1. Modifiable Parameters for U.S. and Europe

U.S.		EUROPE	
Enhancement	User input: Modifiable	Enhancement	Impact on Airport Capacity
Physical Improvement-Additional Runway	**Input additional capacity for IFR and VFR conditions.**	**Arrival/Departure Management**	**Percent capacity increase at constrained airports.**
CTAS	**Decrease interarrival times for arrivals under IFR and VFR conditions.**	**Enhancements arising from Airports and Runway studies**	**Percent capacity increase at constrained airports.**
ITWS	**Increase Maximum number of arrivals per runway, IFR conditions only.**	**Enhanced Wake Vortex Procedures**	**Percent capacity increase at constrained airports.**
WAAS/LAAS	**Percent increase of maximum arrivals to airports, IFR condition only.**	**Use of Automated tools to support Surface Management**	**Percent capacity increase at constrained airports.**
PRM	**Percent increase of arrivals to airports, IFR conditions only.**	**Collaborative Information and Gate Management**	**Percent capacity increase at constrained airports.**
ADS-B (MVFR Enhancement)	**Percent increase for VMS weather conditions.**	**All Weather Operations at airports**	**Percent capacity increase at constrained airports, IFR Conditions.**
ADS-B for Independent Parallel Approaches	**Percent increase of maximum arrivals to airports, IFR conditions only.**		

H.6 OUTPUT

The output of the model is a table containing the detailed results. This table is not in a format that allows for easy display. Currently, the primary method of evaluating and distributing the results is to copy the table from Access and place in a spreadsheet for ease of manipulation. In section 5.0, results are presented after evaluation and formatting in Excel.

The units in the model results are in U.S. pounds, feet, and nautical miles. Conversion to other units is done in a spreadsheet. Results as shown in Tables 5.1-1 through 5.1-8 in Section 5.1 are converted to metric tons.